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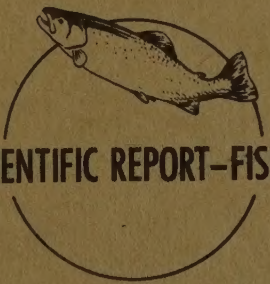
REACTION OF TUNAS TO STIMULI, 1952-53



SPECIAL SCIENTIFIC REPORT–FISHERIES No. 130

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FISH AND WILDLIFE SERVICE

Explanatory Note

The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. It is issued in limited quantities for the official use of Federal, State or cooperating Agencies and in processed form for economy and to avoid delay in publication.

United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

REACTION OF TUNA TO STIMULI, 1952-53

Part I: Response of tuna to chemical stimuli, by Albert L. Tester, P. B. van Weel, and John J. Naughton

Part II: Response of tuna to visual and visual-chemical stimuli, by Sidney C. Hsiao and Albert L. Tester

Special Scientific Report: Fisheries No. 130

Note:--This report is also Contributions Nos. 47 and 48 of the Hawaii Marine Laboratory, University of Hawaii

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PART I

RESPONSE OF TUNA TO CHEMICAL STIMULI

BY

Albert L. Tester, P. B. van Weel, and
John J. Naughton
University of Hawaii

In 1951, exploratory studies of the response of tuna and other fish to chemical, visual, auditory, and electrical stimuli were conducted by P. B. van Weel, S. C. Hsiao, I. Miyake, and A. L. Tester (Special Scientific Report: Fisheries No. 91) of the faculty of the University of Hawaii under contract (No. I6fw-13331) with the U. S. Department of the Interior, Fish and Wildlife Service, Pacific Oceanic Fishery Investigations. It was hoped that these studies not only would contribute to an understanding of tuna behavior but also would provide an indication of ways of attracting tuna to within the reach of a fishing vessel at sea.

Of the various 1951 studies, the most promising was in the field of chemoreception. Van Weel (1952) found that little tunny (Euthynnus yaito) and yellowfin (Neothunnus macropterus) held in captivity responded to clear, almost colorless extracts of tuna flesh.

A new 1-year contract (No. I6fw-18564) for a further study of the reactions of tuna to chemical stimuli became effective June 1, 1952. Efforts were to be made to duplicate and extend van Weel's observations, to identify chemically the attractive substance(s), and to make observations on the reaction of the fish to combined chemical and visual stimuli.

This report deals with the 1952-53 results in the field of chemoreception and includes a brief account of the success attained in fishing and establishing the tunas in captivity.

Note: Contribution No. 47 of the Hawaii Marine Laboratory, University of Hawaii.

The tunas used in the study were caught and transported to Coconut Island by Mr. Lester Zukeran, skipper of the University of Hawaii research vessel *Salpa.* He was ably assisted by Mr. Stanley Kitagawa and Mr. Royden Ikeda, students at the University. In the ponds, the tunas were fed and otherwise cared for by Mr. Charles Nakamoto, assistant to the Hawaii Marine Laboratory, who also took water temperatures and samples of water for chlorinity determination.

At times, Mr. Austin Pritchard and Miss Shirley Trefz, graduate students in marine zoology, assisted in pond testing. Mr. Carl Swanholm, student in chemistry, assisted in preparing and analyzing test materials.

Samples of chemicals were provided gratis by E. I. DuPont de Nemours and Company through Mr. Raoul Pantaleoni, by Van Ameringen-Haebler, Inc., through Dr. Ernst T. Theimer, by P. R. Dreyer, Inc., through Mr. George H. Zirkel, and by Sindar Corporation through Mr. R. E. Horsey.

Mr. Fritz Jermann of Hawaiian Tuna Packers, Ltd., spent many hours preparing materials for testing and assisted in many other ways. Certain materials were also forwarded by Mr. Pete Sunderland of B. C. Packers, Ltd.

To all of these individuals, to the companies they represented, and to others who assisted in various ways we extend our sincere thanks. We are also indebted to Mr. O. E. Sette, Director, and other members of the staff of the Pacific Oceanic Fishery Investigations, U. S. Fish and Wildlife Service, for advice, assistance, and encouragement.

FISHING

As in the previous year (Tester 1952), tuna were caught by trolling with the 46-foot *Salpa,* using two lines suspended from each of two poles fastened to the mast amidships, and sometimes using one or two additional lines fastened to the stern. The ship operated three mornings a week off Kaneohe Bay during the period June 6 to August 31, 1952. As shown in table 1, the catch consisted of 63 skipjack (*Katsuwonus pelamis*), 66 kawakawa or little tunny (*Euthynnus affinis*),[1] 33 yellowfin (*Neothunnus macropterus*), 6 dolphin (*Coryphaenus hippurus*), and 2 wahoo (*Acanthocybium solandri*). The catch per hour (all species) was low in June (1.70) but higher in

---

[1] *Euthynnus yaito* of previous reports (Tester 1952; van Weel 1952).

July (2.36) and August (2.40). The catch per hour for the three months (2.17) was less than that for the same three months in 1951 (3.20).

For tunny and yellowfin, the two species of tuna which we have established in captivity, the catch per hour was higher in 1952 (0.84 and 0.42) than in 1951 (0.40 and 0.31) for a comparable period. For skipjack, however, the catch per hour in 1952 (0.81) was considerably less than that in 1951 (1.48).

Fishing was not continued after August 1, 1952, (except for incidental trips) as the tank and pond were stocked with sufficient fish for our purposes.

Table 1.--The number of fish caught, fishing hours, and catch per hour for the 1952 fishing operations of the Salpa, with comparable data for 1951

Month	Number of fish caught							Fishing hours	Catch per hour
	Skipjack	Frigate Mackerel	Tunny	Yellowfin	Dolphin	Wahoo	Total		
June	21	--	8	6	5	--	40	23-1/2	1.70
July	29	--	29	19	--	2	79	33-1/2	2.36
August	13	--	29	8	1	--	51	21-1/4	2.40
Total, 1952	63	--	66	33	6	2	170	78-1/4	2.17
Total, '51 (June to August)	100	17	27	21	52	--	217	67-3/4	3.20

ESTABLISHMENT OF TUNAS IN CAPTIVITY

Profiting by last year's experience, attempts were made to establish only yellowfin and tunny in the concrete tank and in Pond No. 5, which were used successfully in 1951 (Tester 1952). The tank and pond are located on Coconut Island.

Concrete Tank

The concrete tank, which measures 35 x 11 x 4 feet and is supplied with running seawater by pumps, was modified slightly by rounding the corners with sheets of Masonite and painting the walls white. Despite these improvements only 2 out of 11 yellowfin and 2 out of 13 tunny were established, the former but a short period of time.

Nine yellowfin (3 to 6 pounds) died within 1 or 2 days after introduction to the tank, without starting to feed. One, introduced on June 30 (4 pounds), started feeding on July 4 but was caught and stolen by poachers during the same evening. Another, introduced on July 14 (5-1/2 pounds), started feeding on July 22 but stopped on July 26. In obvious difficulty, it was removed from the tank on July 30 and was found to be blind, with bubbles in the eyeballs.

Eleven tunny (1 to 4 pounds) died within a few days after introduction to the tank. Of these, two started feeding but after 12 days became blind; one died and the other, in obvious difficulty, was removed from the tank. Two tunny, introduced respectively on June 16 and August 15, 1952, became established and lived throughout the winter. They were still alive on June 30, 1953. Both weighed about 1 pound when established and grew to about 4 pounds during the year 2/.

Pond No. 5

This pond, described in detail by Tester (1952), is about 360 feet long and 75 feet wide. The south side is shallow over its entire length, averaging about 3 feet in depth at high water. The north side includes a deep trough, which averages about 10 feet in depth. A slow circulation is effected by tidal action through screened gates at both ends. Both yellowfin and tunny were established in this pond in the summer of 1951 but died during the fall, following wet, stormy weather.

Between July 23 and August 27, 1952, 13 yellowfin (5 to 10 pounds) were placed in this pond. Of these, five started feeding and became established. Four of the 5 disappeared from the pond during the first 2 weeks in September--it is suspected that they were caught by poachers, although they may have died "naturally." In any

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2/ One of these jumped from the tank and died on July 19, 1953. It was partially eaten (by rats or cats?) when discovered, and was not weighed. The other started ramming the walls of the tank and died on July 22, 1953. A film over the eyes indicated partial blindness, which may have contributed to its death when alone in the tank. It weighed 3-3/4 pounds at death.

event, the carcasses were not found. The fifth yellowfin died on September 16, 1952. An additional yellowfin (10 pounds) was placed in the pond on October 28, but it died 5 days later without starting to feed.

Of 15 tunny (1 to 1-1/2 pounds) introduced to Pond No. 5 between July 25 and August 25, 1952, 13 started to feed and became established, despite the fact that several were tagged (the tags later became detached). The remaining 2, which were tagged, died within 2 days. The 13 established tunny were present until October 16, 1952, following which 6 died--3 between October 16 and 20, 2 between October 21 and 27, and 1 between October 30 and 31. The remaining population of 7 fish was maintained until December 5, 1952, when 1 more died. The 6 remaining fish persisted until January 16, 1953. One died on January 16, 2 between January 17 and 20, and 1 between January 22 and 23, 1953. The 2 tunny which remained survived the winter and spring and are still living at the time of writing, more than 1 year after they were introduced. During this period they have increased in weight from about 1 to 4 pounds.

The reason for the mortalities of tunny reported above is uncertain. The temperature and chlorinity in Pond No. 5 are shown in figure 1. The six deaths in October coincided with the beginning of a steep downward trend in temperature and a slight downward trend in chlorinity, both of which were associated with the incidence of rainy weather. However, the four deaths in January cannot be related to changes in temperature and salinity. Moreover, the two remaining fish survived through February and March, when considerable rainy weather was encountered and when the chlorinity in the pond reached a low for the year (15.834 p.p.m. on March 11, 1953).

Although comparable temperature and chlorinity data for the previous year (when all fish died following wet stormy weather) are not available, in general, the winter weather in 1952-53 was much better than in 1951-52, with markedly fewer "kona" storms (south to southeast winds with rain). This may have contributed to the success in maintaining two of the fish throughout the winter. During the one bad storm of the 1952-53 season on October 13 and 14, mortality may have been reduced by tying the Salpa to the dock near the outer gates and flushing fresh water from the pond with the wash of the propeller.

Feeding

In both the tank and pond the tunas were fed during the late afternoon of Tuesday, Thursday, Saturday, and occasionally Sunday, of each week. Their food consisted mostly of tuna flesh

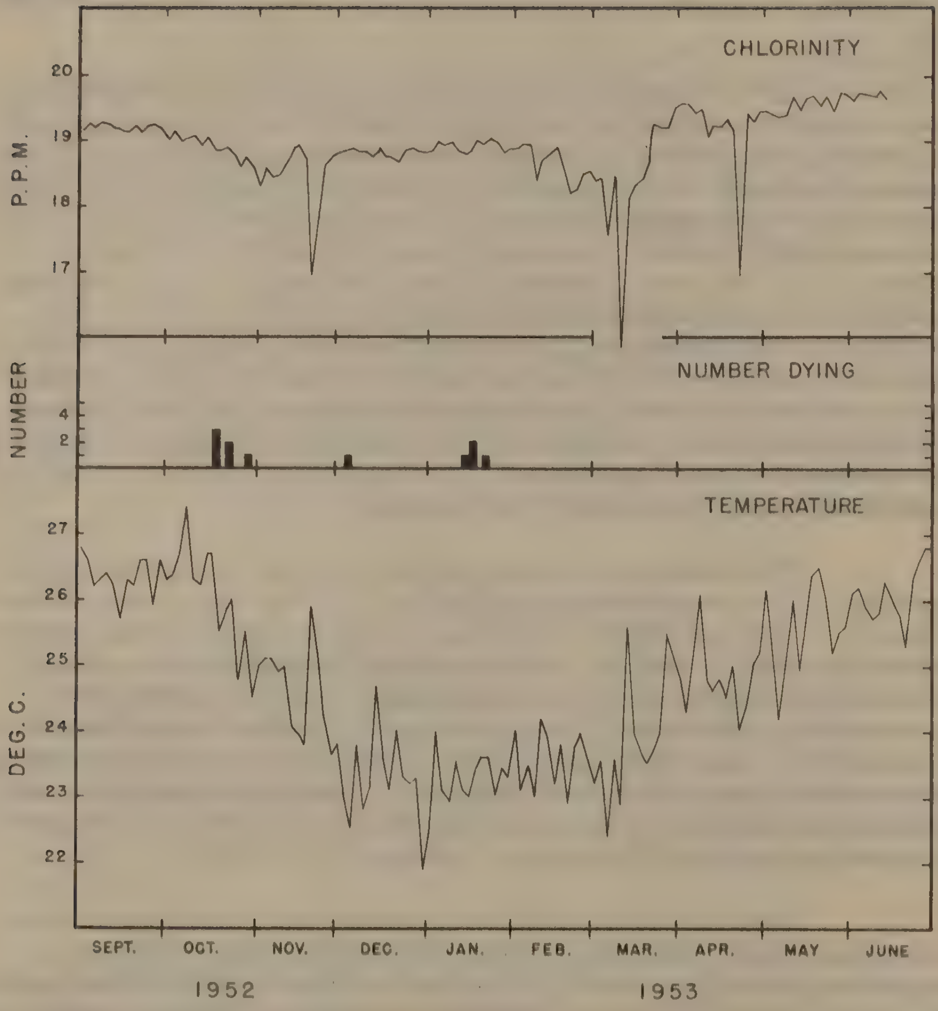


Fig. 1.--Temperature (°C), chlorinity (p.p.m.), and mortality (number of fish dying) in Pond No. 5 over the period from September 1, 1952 to June 30, 1953.

(skipjack, yellowfin, or bigeye) or marlin--whichever was available--plus such other scrap fish as came to hand. In general they were fed at the rate of about one-half pound of food per fish per feeding, which is probably much less than their normal requirement. This schedule was maintained in order that the fish would be in a constant state of hunger on Tuesdays, Thursdays, and Saturdays when tests were usually conducted. Van Weel (1952) showed that this precaution was necessary.

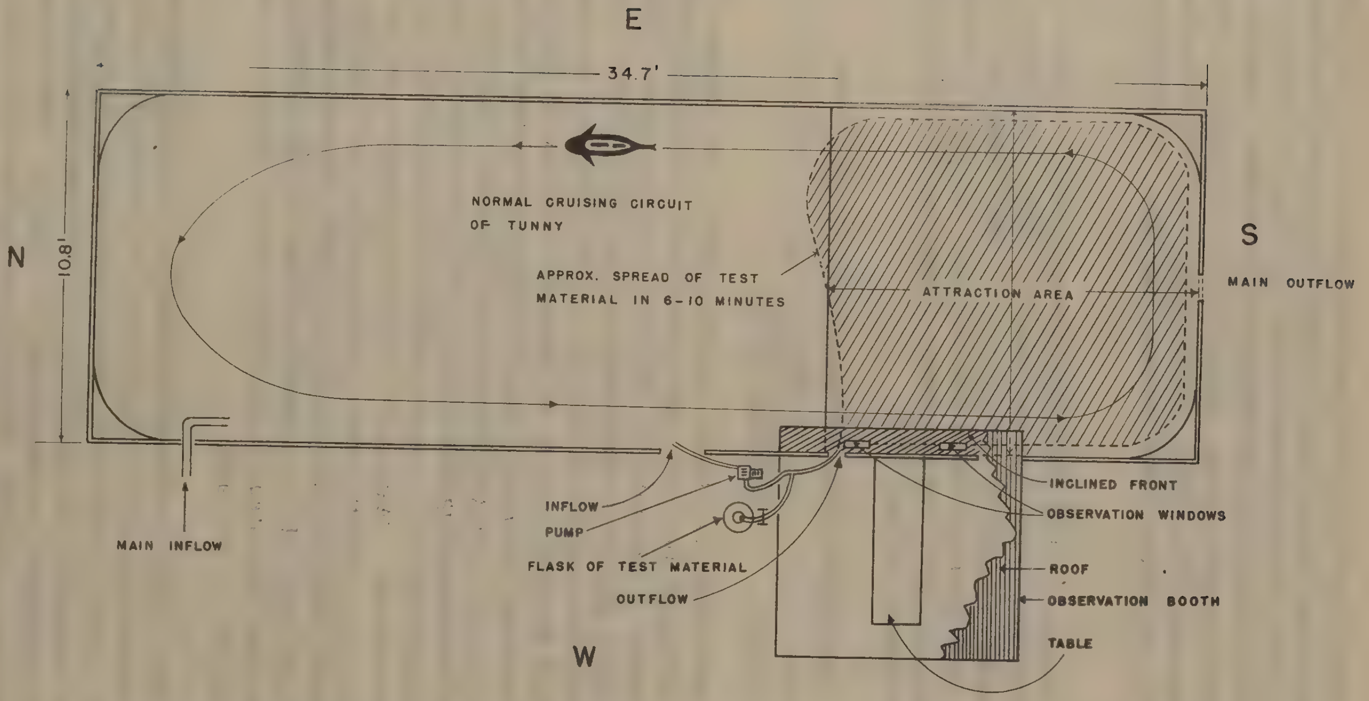
Two departures from this diet are worthy of note. Firstly, the tunny established in the tank on June 16, 1952, was kept on a non-tuna diet, consisting of squid, anchovy, and other fish, until about the middle of July when certain tests had been completed. Secondly, following April 25, 1953, the two tunny in the pond were fed on imported (frozen) squid exclusively.

METHODS AND PROCEDURES IN TESTING

Concrete Tank

Tests were run in the concrete tank 2 or 3 times a week from July 1 to August 20, 1952, and occasionally thereafter throughout the remainder of the summer, the fall, and the winter. At first the methods were similar to those used by van Weel (1952). The observer stood by the railings at the side of the tank near the south end until the fish had become used to his presence and had resumed a steady slow circling. Several successive measurements and counts were made of (a) the time (in seconds) for 10 passes past the observer, with the fish swimming either up or down the length of the tank, and (b) the number out of 10 passes made in the half of the tank adjacent to the observer. Materials were then siphoned into the tank using a rubber hose, and the timing and counting were resumed. Excitement induced when the fish sensed the material was indicated by a decrease in the time of 10 passes (increase in rate of swimming) and attraction was indicated by an increase in the number of passes along the near side of the tank.

Often during attempts to establish control conditions the fish would remain excited for long periods of time by the presence of the observer, whom it could see; during both control and test periods it might also respond to the observer's movements while timing, introducing the materials, or recording the results. This difficulty was largely overcome on July 23, 1952, (following Test 13) by enclosing the upper railed section of the tank with tarpaper and building an observation booth (fig. 2). The three-ply front of the booth overhung the tank at its upper edge to increase the range of vision. It contained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MAIN INFLOW
INFLOW
PUMP
FLASK OF TEST MATERIAL
OUTFLOW
INCLINED FRONT
OBSERVATION WINDOWS
ROOF
OBSERVATION BOOTH
TABLE
W

Fig. 2.--Diagram of the concrete tank showing the arrangement for introducing the test materials, the attraction area, and the observation booth.

two rectangular 6 x 10-inch observation windows the size of which could be varied to a narrow horizontal slit by means of sliding doors. Later, in August, the observation windows were equipped with one-way glass. As nearly as could be determined, the fish were generally unaware of the presence of the observer as long as strict silence was maintained. Occasionally, however, before the glass was used it seemed as if the fish were aware of the small part of the observer's face which was visible through the small slit-like aperture.

By means of a 3/8-inch centrifugal pump driven by a 1/30 h.p. near-silent electric motor, water was sucked from the surface of the tank at one side near the center and was injected into the southern or "downstream" one-third in a continuous stream during both control and test periods. When desired, the test material was introduced into this stream from within the booth through a glass T connection in the rubber tubing.

The method of measuring the reaction was modified from that of van Weel (1952). Each test consisted usually of five successive 2-minute control periods, followed by at least five successive 2-minute test periods. For each period, the time spent by the fish in the downstream one-third of the tank, marked off with string, was measured by an electric clock operated by a push switch, and the number of loops (half-circles) made by each fish in this "attraction" area was recorded on a hand counter. By means of fluorescein dye it was found that a liquid quickly spread throughout the downstream one-third of the tank, remained there for about 10 minutes, and then gradually dispersed up the tank along the far wall. If attracted by the material, the fish would be expected to spend a longer period of time in the attraction area as compared with control conditions. If excited by the material the fish would be expected to swim more rapidly and to circle more times in the attraction area than during control conditions. If a fish entered, turned, and left the area, the count would be one loop. If the fish entered, made a complete circle within the area, and then left, the count would be three loops. If two fish performed in this way, either together or independently, the counts would be doubled. Later the method of counting was modified to conform with that in the pond (see below).

The tests in the tank were conducted for the most part on one established tunny during the summer, and on two established tunny thereafter. Unestablished fish did not react to the test substances and were ignored in timing and counting. A typical series of reaction graphs is shown in figure 3.

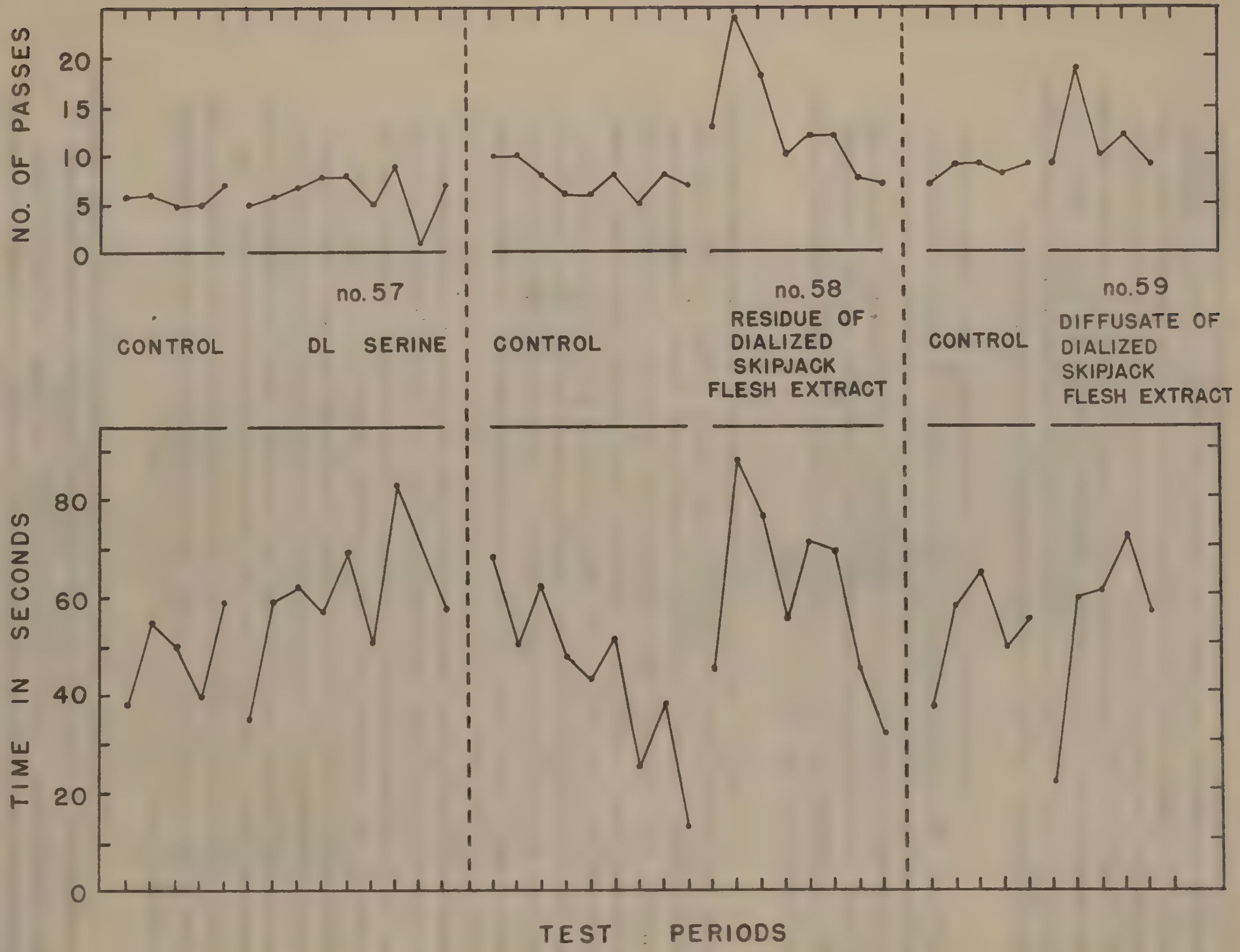

Fig. 3.--Number of passes and time (seconds) out of successive 2-minute periods for three tank experiments--Nos. 57, 58 and 59.

Pond No. 5

When weather and other conditions permitted, tests were run in Pond No. 5 two or three times a week, starting in August 1952 and continuing throughout the fall, winter, and spring. The general arrangement for testing is illustrated in figure 4.

By means of a 2-inch pump driven by a 3-h.p. electric motor, water was sucked from outside the "seaward" gates at the western end of the pond, led through a 2-1/2-inch rubber hose along the concrete gate supports to a point near the center of the deep trough in the pond, and then injected into the pond about 5 feet below the surface (from the high tide mark) through an L-shaped piece of 2-inch galvanized pipe. Test material was introduced into the flow through a funnel, the base of which was attached to a piece of 3/4-inch galvanized pipe by a rubber hose. The 3/4-inch pipe was brazed at an acute angle into a hole in the "down" section of the L-shaped pipe, creating a suction. The funnel was located within a small house erected above the seaward gates, thus effectively screening the operator when waiting to introduce test liquids.

The pump, which was rather noisy and which created a strong visible flow of water for about 20 feet into the pond, was kept running for some time before as well as during both control and test periods to accustom the fish to both the noise and the current. After tracing the path of the current with fluorescein dye, an "attraction" area was marked off with two pieces of cord stretched across the pond, one 39 feet and the other 78 feet from the seaward gates. The dye indicated that liquids introduced into the flow would reach the near edge of this area within about 1 minute, would spread throughout most of the area within about 3 or 4 minutes, and would for the most part remain in the area for an additional 10 minutes before appreciably dispersing downstream across the far cord.

To observe the fish, a wooden tower 20 feet high was built opposite the center of the attraction area on the north side of the pond. A platform and seat on top of the tower was reached by a ladder. As the material was introduced when the fish were starting to return from the far end of the pond, after pouring the material down the funnel the observer was able to move quickly from the small house to the tower, climb the ladder, and sit on the platform before the fish approached the attraction area. It is reasonably certain that he was not noticed by the fish either when moving to the platform or when seated on it. Timing and counting were conducted from the platform. Observation was improved by wearing polaroid sun glasses.

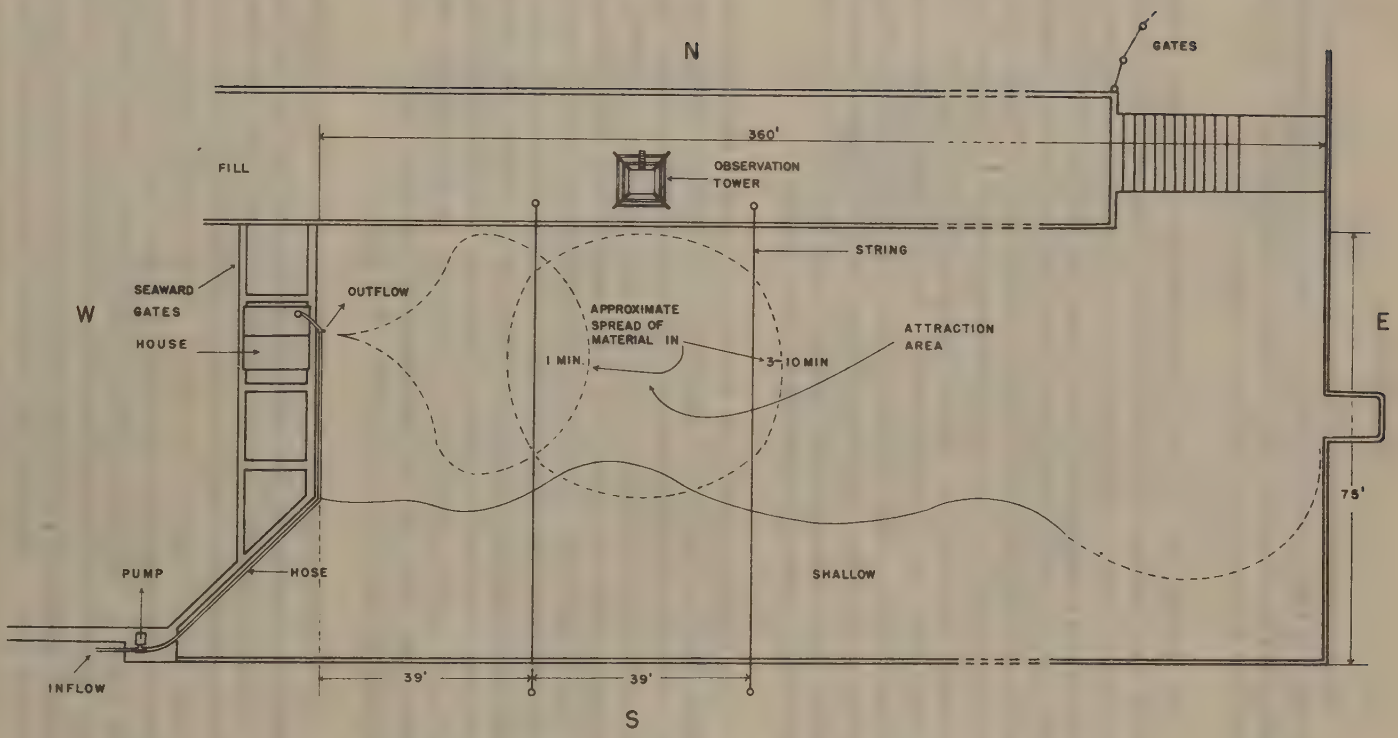
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Fig. 4.--Diagram of Pond No. 5 showing the arrangement for introducing test materials, the attraction area, and the observation tower.

Each experiment usually included five 3-minute control periods and five 3-minute test periods. During each period the time spent by the tunny school or schools in the attraction area was measured on an electric clock operated by a push switch. The switch was depressed when the first fish of a school entered the area and was held down until the last fish left. A fish swimming by itself was ignored; often it was a partially-blind or otherwise incapacitated individual which was unable to keep pace with the others. In addition to timing the fish, each "pass" of each fish in either the upstream or downstream direction was recorded on a hand counter. Thus, if three fish swam through the area, the count would be 3. If they entered the area, looped, and left on the same side as they entered, the count would be 6. If they entered the area, described a complete circle within the area and then left on the opposite side to which they entered, the count would be 9. Time spent in the area was accumulated on the clock and the number of passes was accumulated on the counter. Both were recorded at the end of each 3-minute period. When the tunny population was large (6 to 13 fish), two observers were required on the tower, one of whom climbed down and introduced the test material between control and test periods, and returned when the fish were at the far end of the pond to avoid being seen. When the fish were excited during the early part of a reaction it was difficult to record all the movements, even with two observers; in some cases the counts were minimal estimates. As in the case of the tank, the difference between control and test periods in average time spent by the fish in the attraction area was used as a measure of attraction and the difference in count was used as a measure of the excitement induced by the test substance. A typical reaction graph is shown in figure 5.

In both tank and pond, in addition to the quantitative measure of reaction discussed above, the observer also indicated the strength of the response in one of several "observational" categories (- to XXXX). These will be discussed in a later section.

THE RESPONSE

A summary of data on 356 experiments which were conducted in the tank and pond at intervals over the period July 1, 1952, to May 19, 1953, is given in the appendix at the end of this report. The experiments will be referred to by number, e.g. Nos. 168, 170, etc. The results will be discussed in detail in later sections. For the present, attention will be directed at a description of a typical response in the tank and the pond.

When an attractive substance, such as an extract of tuna flesh, was introduced into the attraction area of the tank, the

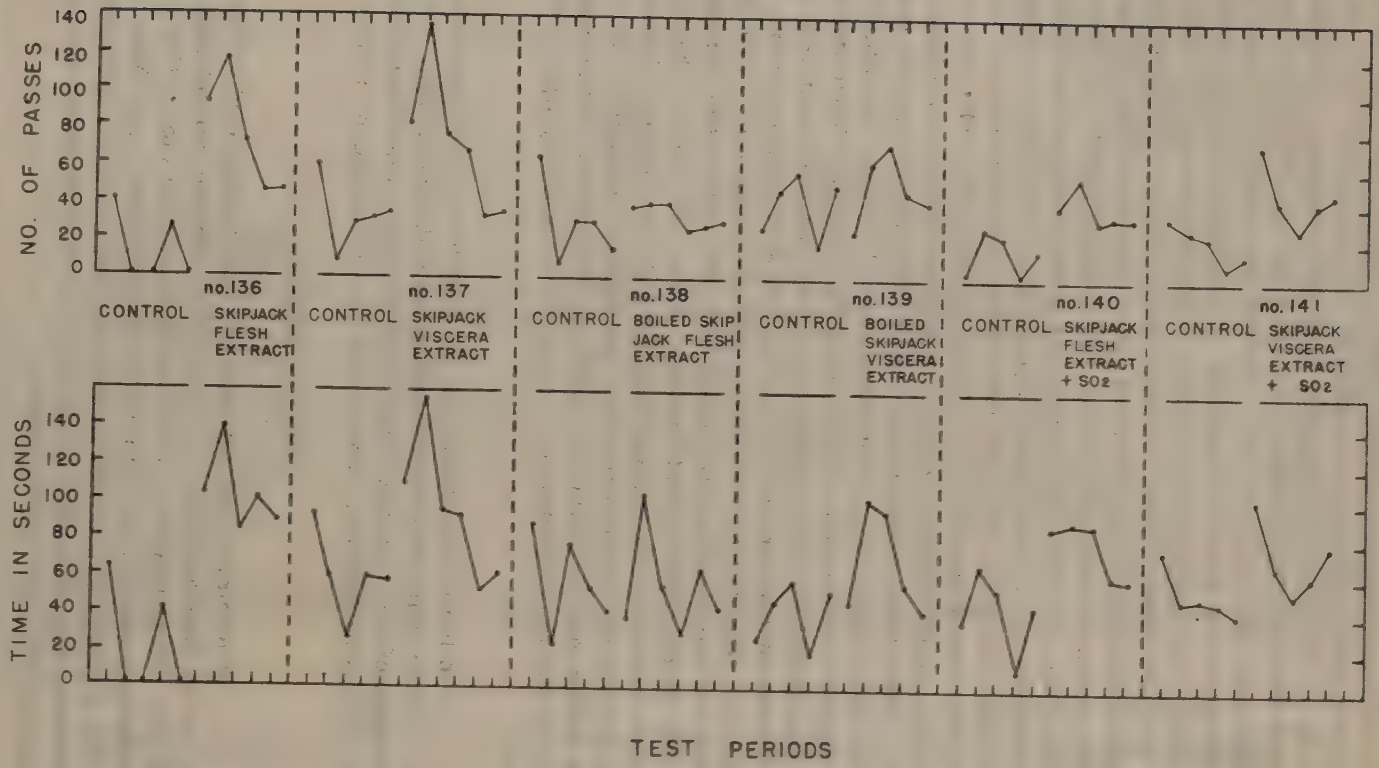


Fig. 5.--Number of passes and time (seconds) out of successive 3-minute periods in six pond experiments--Nos. 136 to 141, inclusive.

material was usually sensed by the tunny in its first pass into the area. Usually the fish would become excited immediately. It would increase its swimming rate, often quickly circling the tank. On returning to the area it would swim rapidly in small circles, splashing and swirling at the surface. At times the fish would flex its dorsal fin and snap with its mouth. Occasionally it would root uneaten food from the bottom and "play" with it (although not eating it as far as could be observed). This excitement would usually be pronounced in the first and second periods (4 minutes from start) but would gradually lessen, until after the fifth period (10 minutes from start) only a more rapid rate of swimming would be noted. If the reaction continued after the fifth period, it would usually take place outside of the attraction area along the far wall, where the material had been carried by the slow, counterclockwise current in the tank.

When an attractive substance was introduced into the pond, a reaction would take place immediately if the tunny happened to be near the point of injection. Usually, however, the material was introduced when the fish were starting to return from the upstream end of the pond. A reaction usually ensued during the first 3-minute period, as soon as the fish entered the attraction area. When several tunny were present, they would immediately depart from a linear, follow-the-leader type of schooling and fan out across the pond, darting into and out of the attraction area at or near the surface, frequently breaking the surface with their backs and creating a "bow wave" as they swam. Often individuals would make short circles in the area, splashing and biting at bubbles, dead leaves, or other objects which happened to be floating on the surface. This activity usually lasted for two periods (6 minutes from start) and often persisted with lessening tempo for five periods (15 minutes from start) or more. When darting into and out of the area, the point at which they turned back seemed to coincide roughly with the dispersion front of the material, the position of which could be inferred from experiments conducted with fluorescein dye. Usually the reaction was over within 15 minutes and normal swimming up and down the pond was resumed. Thus a typical strong reaction was indicated by (a) increased rate of swimming, (b) surfacing, (c) breaking up of usual school formation: a "fanning out" of the school, often followed by independent circling of individuals, (d) return to area after passing through the front of the substance, (e) feeding activity: splashing, lunging, and snapping at objects on the surface.

There was considerable variation in both the pattern and strength of the reaction. Sometimes the fish reacted to the material for but a short time within each period, in the meantime racing the entire length of the pond and quickly returning. When only two tunny were present the reaction was similar to that described in the foregoing paragraph, but was less violent and less spectacular. Even with a larger number of fish, it could vary in its intensity from the very strong reaction described above to a slight sensing of the material - a mere swerving in the area as the fish passed through. Often only one or two (e.g. a and d above) of the five reaction components were evident. Also, of course, many of the substances which were tested gave no noticeable or measurable response.

PROBLEMS IN TESTING

From the foregoing account of the methods, procedures, and response one might assume that precise, clear-cut conclusions could be drawn from each test. This was not the case. There were several uncontrolled variables which affected the results and which made it difficult, and often impossible, to obtain reasonably consistent and comparable data.

Weather

In the tank, when the sky was overcast the fish were difficult to see and hence to time and count. Several experiments were conducted under unfavorable weather conditions, thus introducing an additional source of error in the quantitative data. Testing during rain squalls was usually avoided, for the rain rippled the surface and made observation very difficult. Occasionally, however, rain occurred while experiments were in progress, thus not only changing the conditions for observation of the fish during test as compared with control periods, but also providing a distraction which might affect the reaction of the fish.

These same difficulties were encountered to even a greater extent in the pond, where the water was deeper, and the fish were difficult to see from the tower when swimming deep. Occasionally, visibility was greatly reduced by southeast "kona" winds, which not only created a turbidity but also, blowing lengthwise down the pond, created ripples on the surface. Often, to avoid wasting a whole day, experiments were conducted under such conditions. Although the resulting data were not strictly comparable with those obtained during fair weather, a positive response during test periods could usually be detected as, when reacting, the fish tended to swim at the surface where they could be seen even under unfavorable weather conditions.

Power Failure

During a 2-week period in November 1952, and occasionally at other times, the power supply to the island and/or to the pumps failed. Rather than waste valuable testing time, pond experiments were conducted without the use of the pump. Test material was introduced by throwing it to the surface from the top of the tower when the fish were distant from the attraction area. It was noted that a material which was usually attractive to the fish was not sensed as soon as when introduced by the pump. Apparently it formed a layer on the surface under which the fish could swim without being aware of its presence. When it was finally sensed, it produced a reaction which was stronger than usual, probably because it was more concentrated than when introduced through the flow from the pump. Again, the data would not be strictly comparable with those obtained when the material was introduced in a normal fashion.

Erratic Behavior of the Fish

In the tank under ideal control conditions the fish would make full circles, keeping close to the walls and swimming at a steady rate. They would thus spend about one-third of their time in the attraction area and each would average about 3 or 4 loops in a 2-minute period. However, ideal control conditions were not often encountered. Usually experiments were run when inspection of the control data indicated fair regularity in movement and thus moderate variance in the data, even though the times and counts might differ considerably from the "ideal." At times, particularly when one tunny was the sole occupant of the tank, it would circle for long periods in either the upstream or downstream end of the tank, giving either zero or maximal times and counts. At times it would circle for several successive minutes at one end and would then repeat the performance at the other end. At other times it would swim back and forth along one wall, entering the attraction area either occasionally or not at all. When behavior patterns such as these were encountered, testing was usually abandoned, with consequent loss of time. Occasionally, in desperation, the material was introduced under such conditions, in the hope that the fish would sense it and show some response even though the data would not be comparable with those obtained with more nearly normal behavior. When two fish were present in the tank, even if one was not yet established, the pattern of movement was more uniform and usually yielded control conditions which did not depart excessively from the ideal.

In the pond, the large black yellowfin were more conspicuous and swam more slowly than the small blue-green tunny.

Although their reactions were noted, they were not measured because of the unsuitable swimming behavior. At times they would circle slowly for hours at one end of the pond; at other times they would circle for long periods at one end, move along one wall to the other end, and repeat the performance; only rarely would they move regularly up and down the length of the pond.

Under ideal control conditions, the tunny would swim up and down the pond in one or two schools at a leisurely but regular pace, occasionally pausing to circle or "play" for a few seconds at the ends. A trip down the pond and back usually required about 3 minutes. When joined by the yellowfin, sometimes the faster tunny and sometimes the slower yellowfin acted as pacemakers, thus varying the swimming speed. At times, either of their own volition or attracted by the yellowfin, the tunny would spend long periods of time, sometimes an hour or more, at one end of the pond. When this occurred, experiments could not be conducted for the test material might be diluted below the threshold for response before the fish entered the attraction area. Several experiments were spoiled when, following uniform control conditions and the introduction of the test substance, the fish failed to return to the area within the required time. Even if they entered the area for the first time during the second or third test period, the quantitative data would not be comparable with those obtained during normal behavior.

Measurement of Response

From the sources of variation discussed so far - weather, variation in testing procedure, and erratic behavior of the fish during either control or test conditions - the difficulty of obtaining consistent quantitative data will be apparent. Moreover, the timing and counting did not measure the more obvious characteristics of a complex positive reaction - surfacing, splashing, and feeding activity. On one occasion the response was recorded on motion picture film, a method which might lead to a better quantitative measure. However, this method was not feasible in regular testing because of the great variation in visibility of the fish (depending on weather, turbidity of the water, height of the tide, and depth of swimming of the fish) and also because of the prohibitive cost of the thousands of feet of film that would be necessary to record the many experiments which were conducted.

A series of pond experiments (Nos. 94 to 100, inclusive) has been chosen to illustrate the nature of the data and the problems of statistical analysis and interpretation under average conditions of observation and behavior of the fish. These seven experiments were undertaken in succession throughout the day of August 26, 1952, four in the morning and three in the afternoon. The sky was overcast, with a few rain squalls in the morning. Twelve tunny and four yellowfin were present, but only the former were timed and counted. The nature of the test substances is not pertinent to this discussion.

The basic data are shown graphically in figure 6.

It will be noted immediately that there is a high correlation between the times and number of passes for successive test periods ($r = 0.874$; P less than 0.01). Both variates reflect the reactions almost equally well in this particular series. It will also be noted that in all experiments except No. 98, the times and counts during the test periods are generally higher than during the preceding control periods.

Analysis of variance was employed to determine if there were significant differences between the means of control and test periods (equivalent to a "t" test) for each separate experiment. The results are shown in table 2. It may be concluded that there is a statistically significant response to the test substances of experiments Nos. 95, 97, 99, and 100 (P less than 0.05 or 0.01).

In experiment No. 98 the average time and count during the test periods were both slightly less than during the preceding control periods. Obviously, however, this was due to unusual activity during the controls. To overcome this difficulty a more informative method of analyzing the data is to group all control periods for all experiments as T_0, determine the mean square between means for experiment T_0, to T_7, determine the pooled mean square within experiments, and use this last to determine a least significant difference (fiducial interval) of a treatment mean for comparing not only T_1 with T_0, T_2 with T_0, etc., but also for comparing T_1 with T_2, etc. The analysis, for time data only, is as follows:

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Between treatments	7	16,157	2,308	5.0**
Individual periods	62	28,671	462	

** P less than 0.01

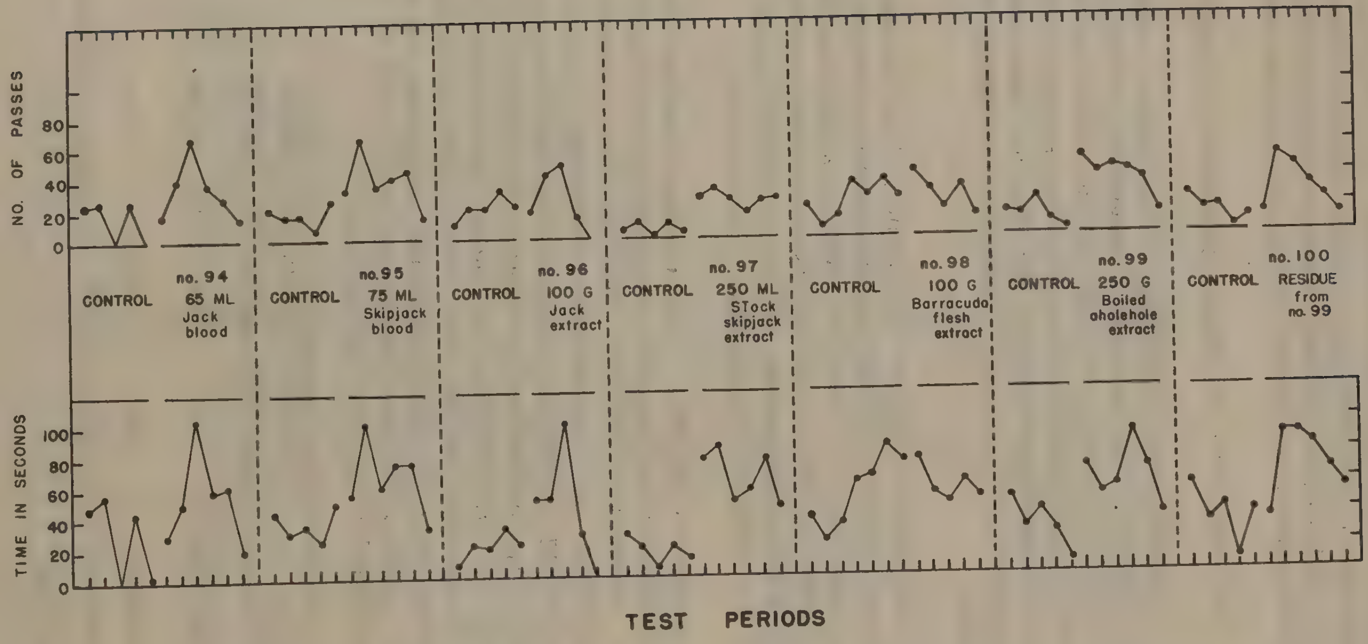


Fig. 6.--Number of passes and time (seconds) out of successive 3-minute periods in seven pond experiments--Nos. 94 to 100, inclusive.

The fiducial interval of a treatment mean may be calculated as follows (Snedecor 1948: p. 221):

$$\pm t_{.05} \sqrt{\frac{s^2}{k_o}}$$

$$= \pm 2.0 \sqrt{\frac{462}{7.14}}$$

$$= \pm 16$$

The mean for the controls is 36.2 seconds; those for the experiments are included in table 2. Again, the means for only four experiments, Nos. 95, 97, 99, and 100, as before, differ significantly (by 32 seconds or more) from the mean for the controls. There are no significant differences between the means for any of the seven experiments. This latter conclusion is also evident from a further analysis of the variance of the combined results:

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Treatment vs. control	1	13,138	13,138	28.2**
Treatment means	6	3,019	503	1.1
Individual periods	62	28,671	462	

The above analysis, based on quantitative data, has demonstrated a significant response in four of the seven experiments. Observation, however, showed a response in all seven, namely, obvious sensing of the material combined with one or more of the several components of the reaction, as described previously. Only in No. 98 was there any doubt; even here, however, there was an obvious change in pace and surfacing of the fish during the first and second test periods. The data and their analyses do not always reflect a response which is obvious and "significant" to the observer. Other experiments could be selected in which the discrepancies between the data and the observations are even more pronounced.

The difficulties outlined above were recognized early. Nevertheless timing and counting were continued: they did measure certain phases of the reaction and have been used in some quantitative

Table 2.--Data on a series of seven experiments (Nos. 94 to 100, inclusive) conducted on August 26, 1952, in Pond No. 5.

Experiment No.	Control means		Test means		Difference		F		Sum of time and count differences	Observed response
	Time	Count	Time	Count	Time	Count	Time	Count		
94	30.8	15.8	60.6	37.8	30.6	22.0	3.2	4.6	52.6	X
95	36.6	17.6	73.0	44.0	36.4	26.4	13.1**	15.5**	62.8	XX
96	38.4	20.8	45.4	24.2	7.0	3.4	0.1	0.1	10.4	X
97	17.6	5.8	68.0	25.0	50.4	19.2	43.0**	42.7**	69.6	XX
98	63.8	27.0	56.8	26.8	-7.0	-0.2	0.6	0.0	-7.2	(X)
99	21.8	13.4	68.2	42.4	46.4	29.0	13.7**	47.7**	75.4	XXX
100	36.0	14.6	73.0	32.4	37.0	17.8	8.0*	5.1*	54.8	XXX

* P less than 0.05 ($F_{.05} = 5.32$; degrees of freedom = 1 and 8)

** P less than 0.01 ($F_{.01} = 11.26$; degrees of freedom = 1 and 8) comparisons; in addition they assisted in maintaining standard tests. Generally, however, reliance was placed on the observer's judgement of a response as gained from visual observation. At the close of each experiment, the strength of a response was recorded in one of several categories (or a fraction thereof) which are designated as follows:

Designation	Numerical equivalent	Description
0	0	No noticeable response.
(X)	0.5	An apparent sensing of the material; of doubtful biological significance.
X	1	A weak but positive response, usually including few of the components (surfacing, speeding, etc.)
XX	2	A moderate positive response, including most components.
XXX	3	A strong positive response, including all components.
XXXX	4	A very strong positive response, including all components; great excitement.

Often a reaction would be indicated by X(X) or XX(X), with numerical equivalents of 1-1/2 and 2-1/2 respectively.

Although admittedly subjective and not well-suited to statistical analysis, the foregoing measure is simpler and at times more meaningful than that dependent on the timing and counting alone. The two observers, by working together, attempted to standardize their judgement of the strength of a reaction. The observed reactions, measured in the above categories, are included in table 2 for the series of experiments analyzed in the preceding paragraphs. They may be compared with the summed time and count differences in the second to last column of the table. There is general agreement between the two measures in that the stronger observed reactions (XX and XXX) are associated with the greater differences between control and test quantitative data. However, there are also notable discrepancies as, for example, in comparing

No. 94 and No. 96: although the observed reaction is judged the same, X, the quantitative data diverge widely (although not significantly according to statistical tests). As will be indicated later, the observer's judgement of the strength of a reaction tended to change with time and with decreased reactivity of the fish. Thus a reaction which might be classed as X in August would likely be classed as XX or XXX in April.

Variation in Response

The strength of the response to an attractive substance, whether measured by the quantitative data or estimated by visual observation, varied greatly from test to test both within and between days. Throughout the mass of data there are numerous examples of this. For example in experiments Nos. 67, 72, 80, 97, 106, 111, 117, and 173, which were all conducted by one observer using the same material (250 ml. stock extract), the response varied from 1 to 3 (X to XXX) on the observational scale.

At times it was suspected that the variation in response was associated with either the frequency of testing or the accumulation of test products. These factors could readily influence the results obtained with fish in the tank, for it had both a small volume and a small rate of flow of salt water. Thus, following four experiments in which relatively large quantities of test substances were used (Nos. 59 to 62), there was no response to a relatively large volume (1,000 ml.) of stock extract (No. 63) in the fifth experiment of the day. After a rest period of 3 days in which no tests were conducted, much smaller volumes (250 ml.) of stock extract gave strong responses (Nos. 81 and 82). In the pond, at times there appeared to be a gradual increase in activity under control conditions and a gradual decrease in response to attractive substances when several experiments were conducted in succession during a day (fig. 5). This may be attributed to several possible causes including chance or random variation, an increasing concentration of materials in the pond, or an increasing threshold of response under repeated stimulation. When a response was protracted beyond the ordinary time limit, usually the observer would wait for 15 to 30 minutes before starting the next experiment to allow the fish to resume normal control activity. To some extent this would overcome the trends which are noted above.

In April 1953 a series of experiments (No. 313 et seq.) was undertaken to determine if there were differences in response to materials maintained at three different hydrogen ion concentrations (T_1--pH 2, T_2--pH 7, T_3--pH 10), but also to investigate the variation in response within and between days. Both the experimental plan and the observational data are included in table 3. Two tunny were present in the pond throughout the 3-week period. Various difficulties were experienced which prevented the completion of all experiments in the series--either erratic behavior of the fish or other difficulties as listed in the footnotes to table 3.

The great variation in response is apparent from the data of table 3. For T_1 and T_2 it ranged from 1/2 to 4, and for T_3 from 1/2 to 2-1/2. A superficial analysis of that portion of the data comprising complete blocks (a.m. only) showed that none of the main effects (order of testing, days, and treatments) was significant. Order of testing contributed the largest mean square, days the next largest, and treatment the smallest. The last was less than the residual mean square. In these and other series of experiments often it has been noted that the first experiment of the day gives the strongest response: the fish are suddenly aroused from a quiescent condition and give a strong response relative to both the preceding control periods and the succeeding test periods. This contributes to the variation between means for order of testing (respectively 2.4, 1.3, and 1.3 for the observational data above). Variation in reactivity from day to day, apart from erratic behavior, has been noted repeatedly by both observers, and is believed real despite the non-significance of the data above. The reason is obscure--it is unlikely that it is related to the state of hunger of the fish; it has been suspected at times that it is related to the weather, tides, or turbidity, but these factors cannot be adequately investigated with the present data.

There seemed to be a decrease in the response and an increase in its variability between the summer of 1952 and the spring of 1953. Thus, in six pond experiments conducted with the same material (each equivalent to about 25 g. of tuna flesh) during August, the mean difference between timing for test and control periods was 32.6 seconds and the range was 11.2 to 52.2 seconds. In the test series conducted in April, in which the material was equivalent to about 350 g. of tuna flesh (14 times as much as before) treated in a different manner but one which did not significantly decrease its attractive properties, the mean difference between the timing for test and control periods was 7.1 seconds with a range of -13.0 to 61.8 seconds. The decreased response was reflected to only a slight extent in the observational data which averaged 1.9 for August and 1.7 for April; apparently there was a change in the observer's judgement of the absolute strength of a reaction. The reason for the decrease in response and the increase in its variability may be related to a decrease in the pond population from 13 to

Table 3.--Observational data on a series of experiments (No. 313, *et seq.*) conducted during April 1953 in Pond No. 5 (T_1--pH 2, T_2--pH 7, T_3--pH 10).

Week	Date	Observer	Treatment-Response						Mean
			Order - a.m.			Order - p.m.			
			1	2	3	1	2	3	
1	4/9	Tester	T_1--4	T_2--2	T_3--2	T_1--2	T_2--2	T_3--1	2.2
	4/11	van Weel	T_1--2-1/2	T_2--1	T_3--1/2	T_1--1-1/2	T_2--1/	T_3--1/	1.4
2	4/14	Tester	T_3--1-1/2	T_1--1	T_2--1	T_3--1	T_1--1/2	T_2--1/2	0.9
	4/18	van Weel	T_3--1/2	T_1--1	T_2--2-1/2	T_3--2/	T_1--1	T_2--1-1/2	1.3
3	4/21	Tester	T_2--2	T_3--3/	T_1--3/	T_2--3/	T_3--1/2	T_1--3	1.8
	4/25	van Weel	T_2--3-1/2	T_3--1-1/2	T_1--1/2	T_2--4	T_3--2-1/2	T_1--2-1/2	2.4

1/ Material lost because of leak in hose.

2/ Fish did not enter attraction area during test periods.

3/ Material not used; fish remained at one end of pond.

2 tunny. This decrease in the number of fish would, of course, decrease the absolute values of the quantitative data, particularly the counts, but it would not necessarily change the difference between control and test data. Apparently 13 fish gave a much greater response than 2 fish to the same amount of material, suggesting a "group" effect--a contagious excitement. On the other hand, the decrease in response may have been related to decrease in the "condition" of the fish and a declining interest in food substances during the winter months.

SOURCE AND PREPARATION OF TEST SUBSTANCES

Materials

The materials which were used are listed for each experiment in the appendix at the end of this report.

Because of its ready availability and also because it had given a positive response in experiments conducted by van Weel (1952), most of the preparations consisted of extracts of tuna flesh, including skipjack, tunny, yellowfin, and bigeye. In addition, extracts of tuna skin, blood, liver, ovaries, testes, and unsegregated viscera were used.

A few tests were conducted with extracts prepared from "white-fleshed" fish (as opposed to the red-fleshed tunas) when materials were available. They included "aholehole" (*Kuhlia sandvicensis*) flesh, jack (*Caranx*) flesh and blood, barracuda (*Sphyraena barracuda*) flesh, and wahoo (*Acanthocybium solandri*) flesh.

The tuna and other fish used in these preparations were either fresh-caught or fresh-frozen. They were obtained from our own fishing operations, from the Pacific Oceanic Fishery Investigations, or from the Hawaiian Tuna Packers, Ltd.

Beef blood obtained from a local slaughter house was used in comparison with fish blood.

Tuna cannery byproducts, including fish meal, stick-water (effluent), and various preserved digests of skipjack viscera made for other purposes by Mr. F. Jermann of Hawaiian Tuna Packers, Ltd., were tested. A herring reduction plant byproduct, "condensed herring solubles" prepared by B. C. Packers, Ltd., Vancouver, Canada, was also used.

As time permitted, tests were run on a variety of organic chemicals purchased from Nutritional Biochemicals Corporation and Eastman Kodak Company. A variety of aromatics used in perfume manufacture and food flavoring were supplied by courtesy of E. I. DuPont de Nemours and Company, Van Ameringen-Haebler, Inc., P. R. Dreyer, Inc., and Sindar Corporation. Miscellaneous substances which were tested included alleged commercial fish attractants and pineapple juice.

Preparation

It is not feasible to describe in detail the method of preparation of each substance which was tested. This has been summarized for each experiment and has been included in the appendix. General techniques and procedures, only, will be discussed here. Where necessary, details of special preparations will be included in later sections.

Simple extracts of fish flesh, skin, gonads, liver, etc. were prepared as follows: a quantity of material (usually about 100 g.) was weighed, cut into small pieces, placed in a Waring blendor with about 200 ml. of sea or tap water per 100 g. of material, and reduced to a homogeneous suspension of finely-divided particles over a 5-minute period. The material was then diluted to about 1 liter with water and was placed in a refrigerator (at about 1° or 2° C.) for several hours. The mixture would be used as such, or it would be separated into liquid and solid components by either filtering or centrifuging before testing.

A "stock extract" of skipjack flesh was prepared in bulk by grinding 9 pounds of flesh in a meat grinder, placing this in a milk can of 10 gallons capacity, adding tap or sea water to nearly fill the can, and placing the can and contents in the refrigerator. The solid material would settle from the liquid in a few hours. The clear, amber to cherry-red liquid (the exact color depending on the proportion of light to dark red meat in the sample) could be decanted from the surface. It was calculated that 1 liter of liquid contained the extract from about 100 g. of flesh. The stock extract could be maintained without putrefaction for 2 or 3 weeks in the refrigerator if the temperature was held just at or above the freezing point. The stock extract was used frequently as a standard in testing other substances.

In most of the experiments conducted during the winter and spring, 95-percent ethyl alcohol was used in the preliminary extraction of ground tuna flesh. The alcohol extract was amber to cherry-red in color as in the case of the water extract. Alcohol served as both an extracting and a preserving agent; refrigeration of the extract was not necessary, although it was used occasionally.

More complex procedures were used in attempts to isolate and identify the attractive substance(s) in extracts of tuna flesh and viscera. These included fractionation of the extract into two or several components to determine, on pond testing, which still retained the attractive properties. In some preparations, a first separation into "protein" and "non-protein" factions was achieved by precipitation of the proteins and similar complex substances. Precipitation was accomplished in various ways, e.g., heating, boiling, saturation with sodium chloride or "salting out", adding tannic and/or phosphotungstic acid, adding the salts of heavy metals such as lead, barium, etc., as well as adding other chemicals to remove those used in precipitation. In other preparations the extract was separated into two fractions by dialysis to determine whether the attractant was comprised of a small molecule which would pass through a dialyzing membrane, or a large molecule which would not pass through a membrane. In still others the extract was divided into a "fatty" and a "non-fatty" fraction, and each was tested in the pond to determine if the attractant was a "fatty" or a "non-fatty" substance. Fractionation was accomplished by removing the fatty acids and similar compounds by extraction with petroleum ether and/or acetone. Other procedures were aimed at determining whether the attractive substance consisted of a positive or negative ion. In these, fractionation was achieved by passing the extract through anion and/or cation exchange resin columns giving two portions, that adsorbed by the column (subsequently removed by elution or washing) and that not adsorbed by the column (the filtrate). In addition, columns of activated charcoal and activated alumina were used to see if they would adsorb the attractive substance.

In many of the preparations, several of the foregoing fractionation procedures were used in succession, each successive portion being tested and being either accepted or rejected for further fractionation depending on whether pond tests indicated that it did or did not include the attractive substance. Several of the procedures were used even though they did not remove the attractive substance; they did remove non-active substances and thus constituted a step in the purification of the attractant. The attractant, when purified as completely as possible by the successive removal of non-attractive substances, was then subject to basic chemical tests in an attempt to determine its basic components and chemical structure.

Miscellaneous chemical compounds were prepared for testing by dissolving in tap water or in weak alcohol solutions, or in the case of fatty or oily substances, by dispersing in water with a dispersing agent "Tergitol". If the latter was not effective, the mixture was forced through an emulsifying apparatus to insure its complete dispersion.

RESPONSE TO SIMPLE EXTRACTS OF TUNA AND OTHER FISH

Flesh Extracts of Tuna

There are many experiments to show that in both the tank and the pond the tunny (and to a lesser extent, the yellowfin) gave a positive response to clear, aqueous extracts of skipjack flesh (Nos. 1, 8, 10, 13, 20, 50, 54, 64, 65, 66, 67, 72, 80, 81, 82, 87, 93, 97, 106, 111, 112, 117, 118, 122, 128, 135, 173, 199, 207), yellowfin flesh (Nos. 14, 18, 26), tunny flesh (No. 27) and bigeye flesh (Nos. 239, 252, 259). To these might be added a large number of experiments using either water or alcohol for extraction in which the materials were subjected to further treatment and which in many cases gave a positive response. In only a few experiments with simple extracts were negative results obtained when positive results were expected. In tank experiment No. 16, the fish had been fed 2 hours previously and were not responsive to skipjack flesh extract. In tank experiment No. 63 there was no response, due probably, as has been mentioned previously, to the dulling produced by an accumulation of test products in the tank with too frequent testing. In pond experiment No. 336, the fish failed to enter the attraction area during the 15-minute test period. In a few experiments, of course, the response was uncertain or slight (X).

The nature of the response to extracts of tuna flesh has already been described. It is a complex reaction, consisting primarily of an urge to feed, which is manifested by speeding, surfacing, circling, snapping at objects, together with a return to the area of stimulation.

It is presumed that in tuna flesh there is present a substance (or substances) which, when extracted and presented to the tunny, can be perceived through the fish's sense of smell or taste. The substance which, when smelled or tasted, promotes the urge to feed is henceforth called the "attractant." Unfortunately, as already pointed out, the response varies greatly in strength or manifestation between similar experiments. It appears to be influenced by many uncontrolled and perhaps uncontrollable factors.

One experiment (No. 112) is described in detail, for it differed from the others in method and purpose. Three liters of stock extract was introduced into the pond, with the pump in operation, by slowly siphoning it into the funnel over a 48-minute period. This established a gradient of attractant from the outlet to beyond the attraction area. Timing, only, was attempted and this consisted of the time out of 3 minutes spent in the first 1/10th of the pond, i.e. the area between the seaward gates and the first string (fig. 4), not including the shallows. The results are shown in figure 7.

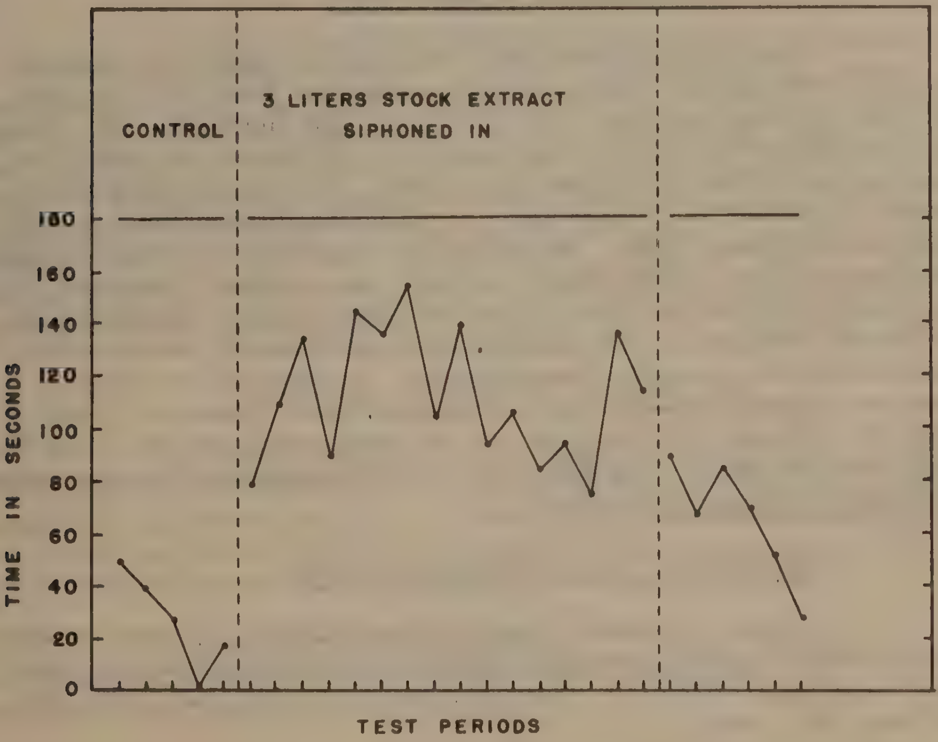


Fig. 7.--Time (seconds) out of successive 3-minute periods in pond experiment No. 112, in which a gradient of stock extract of skipjack flesh was established for 48 minutes.

The material was sensed very quickly by the tunny and produced a typical response, with all components, in the vicinity of the outlet. The response was maintained during the entire time necessary to siphon in the material. A few fish would leave the area and dash down the pond, but they would invariably return to the area of greatest concentration. After all the material had been siphoned in, the response quickly decreased until finally, after about 18 minutes, normal swimming was resumed.

Flesh Extracts of Other Fish

Positive responses were obtained not only to extracts of tuna flesh, but also to extracts of aholehole flesh (Nos. 49, 99, and 105), jack or ulua flesh (No. 96), and barracuda flesh (No. 98). There was no response to wahoo or ono flesh (No. 6), but the fish were not behaving well in this early tank experiment. It is evident that an attractant is present in at least some of the white-fleshed fish, as well as in the red-fleshed tuna. We gained the impression that the response was generally less in these flesh extracts than in those from tuna, but this cannot be proved because of the few experiments conducted with the former, variation in the quantity of material used, and the great variability in the strength of the response. In most of the comparisons the response appeared less (compare Nos. 49 and 50, 96 and 97, 97 and 98, 105 and 106) but in one it was greater (97 and 99). Van Weel (1952) obtained only a weak response to white-fleshed anchovy or nehu (*Stolephorus purpureus*) extract.

Extracts of Tissues Other than Flesh

Strong responses, ranging from XXXX to X, were obtained with extracts of unsegregated skipjack viscera treated in several different ways (Nos. 137, 139, 141, 145, 146, 219, 220, 221, 236, 264, 279, 352, 353, 356).

Excellent responses were also obtained with extracts of skipjack blood (Nos. 43, 70, 95), yellowfin blood (No. 23), and tunny blood (No. 30). Jack or ulua blood (No. 94) gave a positive though weaker response. In contrast to these results beef blood, either whole (Nos. 55 and 74) or the plasma portion (No. 61), was not attractive. In fact, whole beef blood, of a deep red color, was avoided by the tunny in both the tank and the pond experiments--a repellent effect which was probably visual in origin.

Excellent responses were obtained with extracts of yellowfin liver (No. 25) and tunny liver (No. 28).

Extracts of skipjack ovaries (No. 3) and yellowfin testes (Nos. 4, 17) were not attractive. However, whole extracts were used and the fish may have been frightened by the murky cloud which they produced in the water.

Unfiltered extracts of yellowfin skin (No. 24) and tunny skin (No. 29) also formed a dark cloud in the water and were more repellent than attractive. An almost clear centrifuged extract of skipjack skin (No. 48) gave a weak positive response.

It appears that the attractant is present not only in tuna flesh, but also in other parts of the fish. Again, however, it is difficult to come to any firm conclusion as to the relative strength of the response, and thus the relative concentration of the attractant in the various parts. In general the viscera extracts appeared to be at least as attractive as the flesh extracts, and possibly slightly more attractive. In two series of experiments designed to compare extracts of blood, liver, skin, and flesh (Nos. 23 to 26, Nos. 27 to 30), extracts of blood and liver appeared to be more attractive than extracts of flesh, and extracts of skin appeared to be less attractive.

Cannery Byproducts: Preservation

Good (XX) responses were obtained with extracts of tuna fish meal, both boiled (No. 119) and not boiled (No. 120) during extraction. Excellent responses (XXX) were obtained with tuna stickwater both by itself (No. 217) or mixed with fluorescein dye to trace its dispersion in the pond (No. 222).

"Condensed herring solubles," a product derived from the stickwater of a herring reduction plant (B. C. Packers, Ltd.) was not sensed by the fish (Nos. 328 and 329).

Several experiments were run on skipjack viscera preparations submitted by Hawaiian Tuna Packers, Ltd., with excellent results (XX to XXXX). In all preparations the viscera from the cannery were first ground in a meat grinder. In some they were preserved in 2- or 3-percent sulphur dioxide and self-digested, producing a particulate portion which settled to the bottom of the container and a supernatant dark brown liquid (Nos. 219, 221, 290, etc.). In others, the ground viscera were steamed at 20 pounds pressure and preserved in 3-percent phosphoric acid, again producing a solid and a supernatant yellow liquid (No. 220). A ground viscera preparation preserved in 2-percent sodium bisulphite and digested with pepsin gave little evidence of attraction in three tests (Nos. 258, 260, and 263). Apparently loss of attraction was due to something associated with pepsin digestion rather than to the use of sodium bisulphite, for this preservative was used successfully in other preparations (Nos. 264, 279, etc.).

The above results, indicating that the attractive qualities are not lost when the materials are preserved in chemicals, are in accord with those obtained with our own preparations which were tested at an earlier date. Skipjack viscera extracted with water and treated with 2-percent sulphur dioxide (Nos. 140, 141), with 2-percent sulphuric acid (No. 144), or with 2-percent phosphoric acid (No. 145) were still attractive to the fish even after being kept at room temperature for several days.

RESPONSE TO CHEMICAL COMPOUNDS AND MISCELLANEOUS MATERIALS

As time permitted, a variety of chemical compounds ranging from amino acids to proteins and including vitamins and various miscellaneous aromatics were tested as follows:

Arginine (No. 32, 103)

l-Asparagine (No. 102)

Creatine (No. 109)

l-Glutamic acid (No. 191)

Glycyl-glycine (No. 127)

l-Histidine monohydrochloride (No. 192)

dl-Isoleucine (No. 34)

l-Leucine (No. 44)

Methionine (No. 157)

dl-Norleucine (No. 45)

dl-Phenylalanine (No. 31)

dl-Serine (Nos. 51, 56, 101, 104, 108)

l-Taurine (No. 42)

Acetyl tryptophane (No. 176)

l-Tyrosine (No. 33)

dl-Valine (No. 41)

Isoeugenol (No. 37)

Nucleic acid (No. 110)

Histamine diphosphate (No. 198)

Adenosine (No. 242)

Adenosine triphosphate, disodium salt (Nos. 243, 254, 271)

Adenosine diphosphate, barium salt (Nos. 245, 255, 270)

Adenylic acid (No. 244)

Trimethylamine oxide (No. 188)

Animal lecithin (No. 129)

Albumen (No. 62)

Peptone "I" (No. 189)

Vitamin B_{12} (No. 166)

Acetyl choline chloride (No. 192)

Pregnenolone (No. 132)

Ambergris (No. 131)

Anethol (Nos. 22, 71)

Phenyl acetic acid (No. 251)

Alpha ionone (No. 158)

Alamask (No. 172)

Furfuryl mercaptan (Nos. 231, 241)

Coumarin (No. 249)

Methyl anthranilate (No. 250)

Meat flavor (No. 253)

Pineapple juice (No. 168)

Eosin B (No. 36)

Methylene Blue (No. 38)

None of the above substances gave a positive response which could be verified. In some, however, there appeared to be a sensing of the substance as will be discussed below.

Among the amino acids, serine appeared to give a weak positive response in one tank experiment (No. 51) and a very weak positive response in another (No. 56). In three pond experiments, there appeared to be a sensing of the material in one (No. 101) but not in two others (Nos. 104 and 108). On the same day on which the fish appeared to sense the serine in the pond (No. 101) they also appeared to sense asparagine (No. 102) and arginine (No. 103), suggesting that they were in a particularly responsive condition. On another occasion they appeared to sense methionine (No. 157). Apparently the fish were aware of the presence of the substances but the slight reaction seemed to be one of curiosity rather than attraction: certainly it lacked the features of a typical response.

This same sensing of material was noted in the case of certain strong-smelling aromatics, e.g., anethol (No. 22), "meat flavor" (No. 253), and particularly furfuryl mercaptan (Nos. 231 and 241). The first substance, which has a licorice smell, is the active ingredient of oil of anise, a reputed fish attractant; the second is a strong, spicy, pleasant-smelling artificial flavor; the third is a very foul-smelling chemical of great potency. A similar response was noted with odorless vitamins, B_{12} (No. 166) and acetyl choline chloride (No. 192), and also with ordinary pineapple juice (No. 168). Again, however, the response seemed to be one of curiosity.

The series of experiments with adenosine, adenosine compounds, and adenylic acid was conducted in an attempt to determine if the attractive substance was one which is present in mammalian muscle. That it might be was suggested by chemical tests of the attractant (see later) which showed the presence of phosphorus and the amide link. The substances were dissolved in sea water immediately before testing to avoid hydrolysis. The barium salt of adenylic diphosphate was dissolved in 0.1 N hydrochloric acid and the barium was precipitated with 6N sulphuric acid to have it present as free adenosine diphosphate acid, rather than as a barium salt (there had been indications that barium tended to destroy the attractive material). It was presumed that the pH of seawater would assure the proper molecular form of the sodium salt of adenosine triphosphate. First tests indicated a sensing and an attraction of the tunny to both adenosine triphosphate (No. 243) and diphosphate (No. 245) but not to adenosine (No. 242) nor to adenylic acid (No. 244). However, later tests with both the triphosphate (Nos. 254 and 271) and the diphosphate (Nos. 255 and 270) gave negative results.

The two dyes, eosin red (No. 36) and methylene blue (No. 38), were visually repellent to the fish. This same reaction, an avoidance, was occasionally noted with strong solutions of the greenish fluorescein.

In addition to the substances listed above, two alleged fish attractants were tested, one known as "Slik" which smelled of cod liver oil, and the other an unnamed "fish lure" which smelled of tuna or herring viscera extract. There was a slight sensing of the first (No. 174) and a weak but positive reaction to the second (No. 349).

ATTEMPTS AT ISOLATION AND IDENTIFICATION OF THE ATTRACTANT (S)

The attractant(s) was initially segregated from the flesh or other parts of the fish by virtue of its solubility in water. Thus, on centrifuging, the aqueous extract of finely-divided tuna flesh formed a clear amber to reddish colored solution which usually caused a strong positive response (Nos. 1, 8, 10, and numerous other experiments in both tank and pond). The residue from centrifuging was either attractive (No. 15) or not (No. 2), depending on either the thoroughness of the extraction or the part played by vision in the case of the murky mixture.

In early tank experiments, boiling of tuna flesh with water, thus precipitating the proteins and similar compounds, appeared to remove or destroy the attractant. The clear filtrate from the boiled flesh failed to elicit a response (Nos. 5, 9, 11, 12, 21) as was also found previously by van Weel (1952). However, as will be discussed later, this was not the case with boiled extract of flesh.

Dialysis, using a cellophane tube (1-5/8 inch diameter), was next tried in an attempt to segregate the attractant, using clear aqueous extracts of skipjack flesh (several experiments) or tunny blood (one experiment). In all cases the dialyzate gave a positive response when tested (Nos. 39, 46, 53, 57, 90, 118, 123), showing that the attractant consists (in part, at least) of a small molecule, rather than a large molecule such as a protein. In no case, however, was complete separation attained by dialysis. In most of the experiments the residue (portion remaining in the tube) gave a stronger response than the dialyzate (compare Nos. 39 and 40; 52 and 53; 57 and 58; 90 and 91) despite several changes of the distilled water surrounding the tube.

Precipitation of the proteins by dilute (10-percent) hydrochloric acid was next attempted. After the centrifugate of an aqueous extract of skipjack flesh was treated with acid and centrifuged, both the neutralized centrifugate (No. 68) and the neutralized residue (No. 69) gave positive responses, showing incomplete separation of the attractant.

As the above results indicated that the attractant was not a protein, a series of pond experiments was undertaken in which the proteins were precipitated by heating. On heating the centrifuged aqueous extract of skipjack flesh to 69° C., a precipitate appeared. When this was removed by centrifuging, the centrifugate was still attractive (No. 76). When the centrifuged aqueous extract was boiled for 30 minutes, resulting in a heavy precipitate, both the filtrate in one experiment (No. 77) and the centrifugate in another (No. 78) were still attractive to the fish. However, separation was not complete, as is shown by the weaker positive responses obtained with the washed residue from centrifuging (compare Nos. 75 and 76; Nos. 78 and 79).

It is uncertain why the filtered extract of boiled tuna flesh failed to give a positive response in the earlier tank experiments Nos. 5, 9, 11, 12, and 21). Although the behavior of the fish in the tank was not too satisfactory, it seems certain that had a response occurred, it would have been noted or measured in one of the five experiments. It is unlikely that the attractant was destroyed by boiling in view of the results reported in the preceding paragraphs and others to be presented later. There remains the possibility that the attractant was precipitated with the soluble proteins or otherwise adsorbed with the insoluble proteins during the process of boiling the flesh; the residue, which may have contained the attractant, was not tested in the five experiments conducted with the boiled flesh.

Chemical tests were run on the clear centrifugate obtained after boiling of the extract. The Biuret test was positive, showing the presence of the amide link. The Xanthoproteic test was positive, indicating the presence of the benzene ring. No positive test for protein was given on layering the solution over concentrated nitric acid. The lead test for sulphur was negative.

A series of experiments was conducted to compare the effects of precipitation by boiling and precipitation by salting out of the proteins on the attractiveness of the filtrate. The procedure and results are depicted in figure 8. Clear stock extract was boiled for 15 minutes and centrifuged; the centrifugate was divided into three equal parts, the first of which was tested (No. 85), the second of which was saturated with sodium chloride, centrifuged, and both centrifugate (Nos. 83, 86) and residue (No. 88) tested, and the third of which was boiled for an additional hour, centrifuged, and the centrifugate tested (No. 84). Strong responses were obtained with all tests except that with the residue (No. 88). The attractant was not removed with precipitation in either boiling or salting. Apparently fractionation was complete when both boiling and salting were used (compare Nos. 83 and 86 with No. 88).

The boiling and salting procedure was carried one step farther in two additional experiments. The centrifugate, after boiling and salting, was boiled to a residue. When re-dissolved in seawater, a positive response was obtained (Nos. 113, 121).

The possibility of precipitating or destroying the attractive substance by heat after it had been segregated in a relatively pure (protein-free) state by dialysis was next investigated. One liter of the dialyzate from a stock extract was boiled to 10 ml. and tested, producing a very strong response (No. 118). The residue from dialysis was boiled to a gummy residue, producing weaker but positive responses with both the 95-percent alcohol soluble portions and the alcohol insoluble portions (Nos. 114, 115, 116). In a second series, the dialyzate was boiled to dryness and a strong positive response was obtained with the portion of the residue which was soluble in absolute ethyl alcohol (No. 123). The solubility in absolute alcohol was confirmed in later experiments (Nos. 201, 281).

Thus the attractant is a substance comprised of a small molecule which is (at least, partly) soluble in absolute ethyl alcohol. This property rules out most of the known amino acids (except methionine and proline). However, that part of the attractant or attractants was insoluble in alcohol yet soluble in water is indicated by several experiments in which the alcohol-insoluble, water-soluble portion gave a positive response (Nos. 115, 116, 124, 183).

Because of the time required for dialysis and the incomplete separation that was achieved, attention was directed at

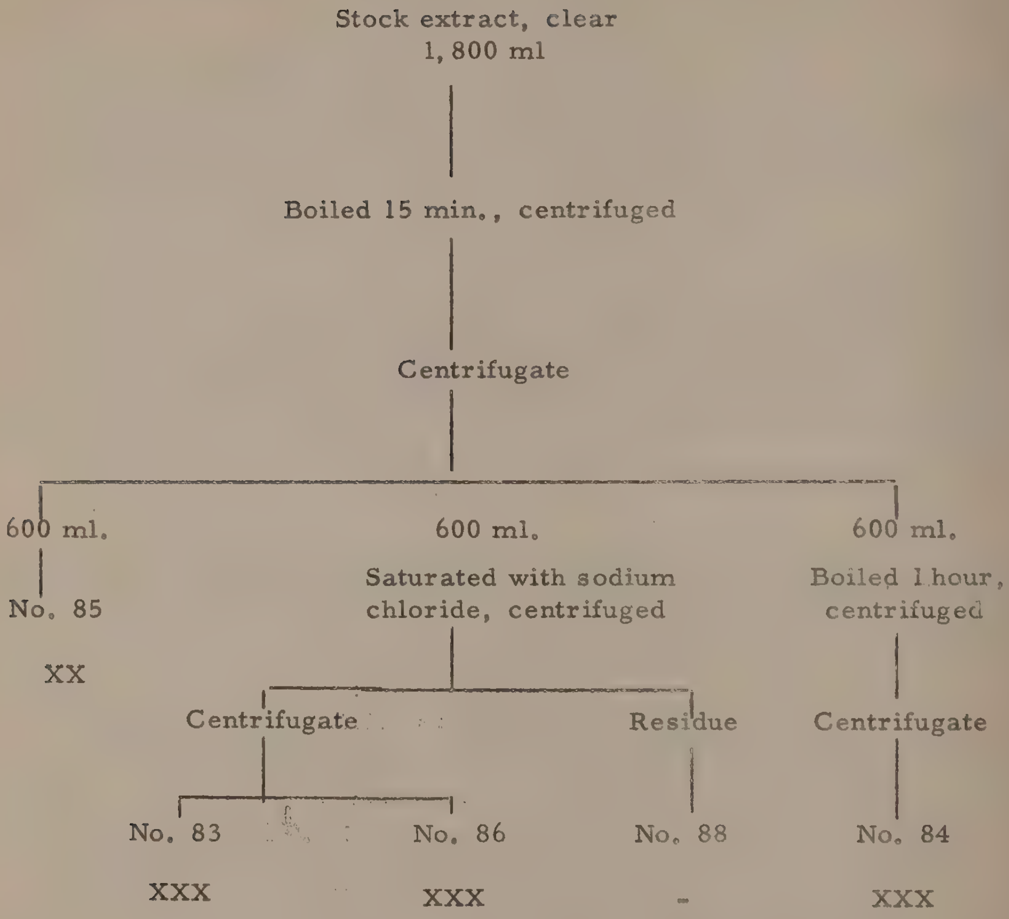

Stock extract, clear
1,800 ml
Boiled 15 min., centrifuged
Centrifugate
600 ml.
No. 85
XX
600 ml.
Saturated with sodium chloride, centrifuged
Centrifugate
No. 83
XXX
No. 86
XXX
Residue
No. 88
-
600 ml.
Boiled 1 hour, centrifuged
Centrifugate
No. 84
XXX

Figure 8.--Fractionation of stock extract of skipjack flesh: procedure and results in experiments Nos. 83 to 86, and 88.

the possibility of adsorption on various media. In one experiment, stock extract was concentrated by boiling, filtered, boiled with activated carbon, filtered, evaporated to a gummy residue, redissolved and tested, giving a positive response (No. 125). In another, the same procedure was followed except that after boiling with activated carbon the filtrate was treated with activated alumina, again with a positive response (No. 130). Similar results were obtained with anion (No. 133) and cation (No. 134) exchange resins. Apparently the attractant was not (completely) adsorbed on any of these media.

At this time (September 1952) the chemical work was undertaken at the University of Hawaii rather than the Hawaii Marine Laboratory; the tests, of course, were continued on the fish in Pond No. 5 at Coconut Island. To obviate the need for refrigeration and to facilitate condensation, extracts were prepared with 95-percent ethyl alcohol instead of water. The actual strength of the alcohol in the extract was less than 95-percent, depending on the quantity of water in the flesh and the relative quantities of flesh and alcohol which were used, but it was always strong enough to act as a preservative at room temperature. Numerous experiments showed that this alcohol extract promoted a strong positive response (Nos. 147, 163, 180, 235, etc.), whereas there was no response to alcohol alone (No. 19). However, complete extraction of the attractive substance with alcohol was difficult to attain. In two experiments, the flesh was treated with 95-percent alcohol for several hours and the alcohol, containing some of the attractant, was filtered off and used for further fractionation. The flesh was again treated with alcohol, and the alcohol filtered off and used. The flesh was then treated with water and the filtrate was tested. It still gave a strong response (Nos. 164 and 169) showing that the attractant had not been completely removed by the previous two alcohol extractions. To see if complete separation could be achieved with alcohol extraction, flesh was extracted twice with 95-percent alcohol as above. It was then further extracted with alcohol for 14 hours in the Soxhlet apparatus. The alcohol was then removed, and the flesh was extracted for an additional 12 hours with distilled water. The centrifuged water extract gave only a slight response (No. 17), indicating that almost complete extraction of the attractant had been achieved by the previous alcohol treatments.

Further attention was directed at fractionation of the alcohol extract by use of various adsorption media. To improve the technique, columns of the adsorbing media were prepared, through which the extract was allowed to filter slowly. Two portions were obtained, the filtrate or material which filtered through the column without being adsorbed, and the eluate or portion which was adsorbed on the column and which was eluted or washed from it with various solutions such as water, weak acids, weak bases, alcohol, acetone, etc.

In a series of experiments with columns of activated alumina, zeolite, and activated carbon (Nos. 149 to 154) positive responses were obtained from both the filtrate and (water) eluate of the alcohol extract of skipjack flesh. However, the attractant appeared to be adsorbed most on activated alumina (No. 150) and least on activated carbon (No. 153). Adsorption on activated alumina was obtained in two additional experiments (Nos. 156 and 165), but complete separation of the attractant was not achieved (Nos. 155 and 162). Attempts at fractionation with alumina were abandoned in favor of anion and cation exchange columns.

Small white crystals which appeared in the (acetone) eluate from the activated carbon column, when dissolved in water, appeared to cause a positive response (No. 159). Further preparations gave no response (No. 167) and a doubtful response (No. 171). It was concluded that the positive responses were apparent rather than real and that the white crystals were not attractive. The attractive substance, for the most part, appeared in the filtrate from the carbon column. Thus either mixing or boiling activated carbon with the extract or passing the extract through a carbon column would remove certain inactive substances and constitute a stage of purification. This procedure was followed in some of the later preparations.

Another step in purification was the removal of fatty acids and related compounds which were soluble in petroleum ether or acetone. Van Weel (1952) found that the attractant was not soluble in petroleum ether. This finding was verified (Nos. 18, 142, 175, 177, etc.). It was also found that the attractant was not removed by extraction with acetone (No. 142).

Still another step in purification was the removal of inactive proteins by precipitation with tannic acid (No. 215), lead acetate (No. 197; Nos. 200 to 206; etc.), or barium acetate (Nos. 211, 212, 225) and the removal of purines and similar compounds as silver salts (Nos. 183, 184) or with phosphotungstic acid (No. 193, etc.).

Some of the above steps in purification either preceded or succeeded fractionation by adsorption on anion or cation exchange resins. Many different experiments, employing one to several successive stages of purification, were conducted. Two typical series only will be discussed to illustrate the procedure and results. Others may be followed from data given in the Appendix.

The first, a relatively simple series designed to determine whether the charcoal-purified, "fat-free" attractant was adsorbed on ion exchange resin columns, is illustrated in figure 9. An alcohol extract of skipjack flesh was passed through a column of activated charcoal; the filtrate was evaporated to dryness and extracted with petroleum ether and the residue was dissolved in alcohol and divided into two portions. One portion was passed through a Duolite C-3 cation exchange resin column and the filtrate collected and tested (No. 178); the column was then eluted with 5-percent sulphuric acid and the eluate was collected and tested (No. 181). The other portion was passed through a Duolite A-3 anion exchange resin column, and the filtrate was collected and tested (No. 179); the column was then eluted with 5-percent sodium hydroxide and the eluate was collected and tested (No. 182). In this particular series all tests were positive, but the eluate from the anion column (No. 182) appeared to give the strongest response.

The above results indicated that a further investigation of the adsorption on an anion column would be profitable, particularly to see (a) if complete adsorption of the attractant could be attained, (b) to see if the adsorbed material was completely removed by a water eluate, or if additional adsorbed material could be recovered with either a weak base or a weak acid and (c) to examine the solubility of the attractant in absolute alcohol. The series is illustrated in figure 10. A clear alcohol extract of tuna flesh was treated with lead acetate to remove proteins, filtered, and the filtrate was extracted with petroleum ether; it was then treated with hydrogen sulphide gas to precipitate the lead and excess gas was removed in vacuum. The filtrate was passed twice through a Duolite A-3 anion exchange resin column and the filtrate collected and tested (No. 200). The column was then eluted, first with water, next with a weak acid, and finally with a weak base. The water eluate was evaporated to dryness and dissolved in absolute alcohol (No. 201); the residue was dissolved in water (No. 202). The base eluate was similarly treated, giving an alcohol soluble portion (No. 204) and an alcohol-insoluble, water-soluble portion (No. 205). A positive response was obtained only with the alcohol soluble portion of the water eluate. In this series it appears that complete separation of the attractant was achieved by use of the anion exchange column and that the adsorbed attractant was completely removed by the water eluate.

In these and other experiments conducted during the autumn, it appeared that the attractant, purified to a varying extent, was not adsorbed on a cation exchange column, for positive responses were obtained with the filtrate (Nos. 142, 178, 216, 225) rather than the eluate. Only two tests were performed with the latter, however, one

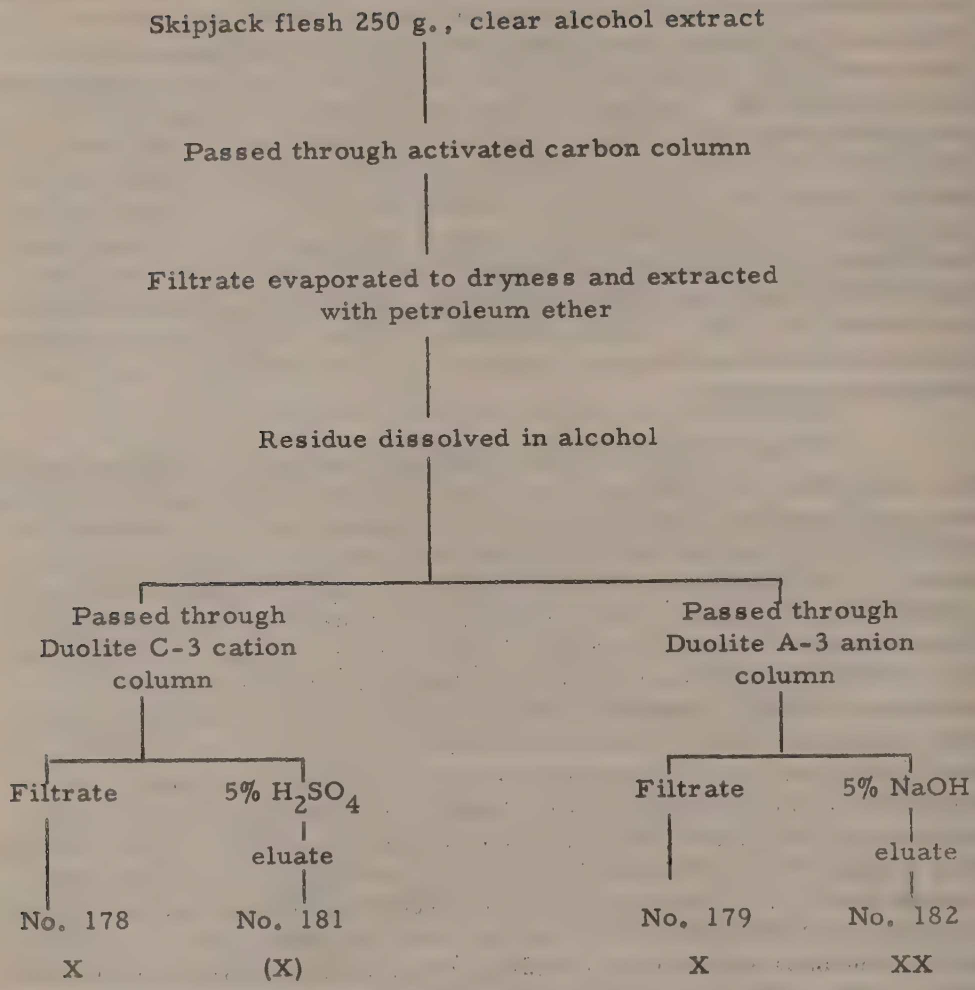
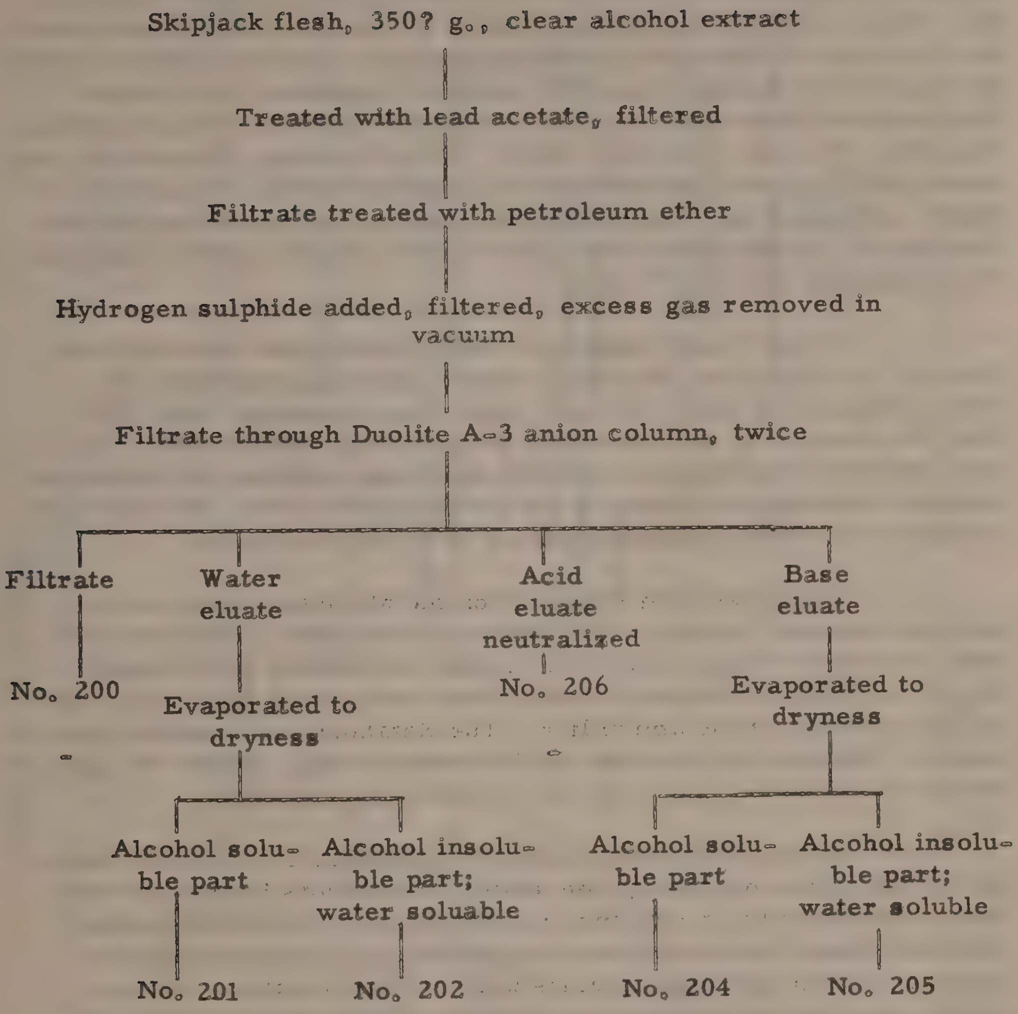

Skipjack flesh 250 g., clear alcohol extract
Passed through activated carbon column
Filtrate evaporated to dryness and extracted with petroleum ether
Residue dissolved in alcohol
Passed through Duolite C-3 cation column
Passed through Duolite A-3 anion column
Filtrate
5% H2SO4
eluate
Filtrate
5% NaOH
eluate
No. 178
X
No. 181
(X)
No. 179
X
No. 182
XX

Figure 9.--Fractionation of an alcohol extract of skipjack flesh: procedure and results in experiments Nos. 178, 179, 181, and 182.


Skipjack flesh, 350? g., clear alcohol extract
Treated with lead acetate, filtered
Filtrate treated with petroleum ether
Hydrogen sulphide added, filtered, excess gas removed in vacuum
Filtrate through Duolite A-3 anion column, twice
Filtrate
Water eluate
Acid eluate neutralized
Base eluate
No. 200
Evaporated to dryness
No. 206
Evaporated to dryness
Alcohol soluble part
Alcohol insoluble part; water soluable
Alcohol soluble part
Alcohol insoluble part; water soluble
No. 201
No. 202
No. 204
No. 205

XX

Figure 10.--Fractionation of an alcohol extract of skipjack flesh: procedure and results in experiments Nos. 200 to 202, and 204 to 206.

giving no response (No. 143) and the second giving a slight response (No. 181). More attention was directed to the anion exchange column, for it seemed to adsorb the attractant in several experiments as shown by moderate to strong (X and XX) positive responses with a water, dilute sodium hydroxide, or dilute ammonium hydroxide elutant (Nos. 182, 185, 193, 194, 201, 208, 213). Up to this stage of the study, the eluate failed to give a response in only two tests (No. 196 and 223) in which a response was expected on the basis of the preceding results. The filtrate, on the other hand, gave either a weak positive response or no response (Nos. 179, 200).

It was clear, however, that the attractant was held very "loosely" on the anion exchange column, appearing mostly in the first portion of the water or weak base eluate (compare Nos. 185, 186, 187; Nos. 208, 209, and 210; 213,214; 246, 247 and 248). The weak affinity (possibly not a true ion exchange) explains the failure of complete separation in some of the above experiments, and may have contributed to certain inconsistencies to be reported later.

Chemical tests were run on the attractant in its purest form yet attained, namely, that portion of the water eluate from the anion exchange column which was soluble in absolute ethyl alcohol (No. 201). Both the Biuret and Ninhydrin tests were positive, showing the presence of the amide link. The Xanthoproteic reaction was positive, showing the presence of the benzene ring. A test for phosphorus was positive, but a test for sulphur was negative.

In subsequent experiments which were run from the latter part of December on through the winter, the results became erratic. There was difficulty in obtaining meaningful and consistent results with the various chemicals used in purification, and also with the anion and cation exchange columns used in fractionation. For example, when barium acetate was substituted for lead acetate to precipitate the proteins and the filtrate was treated with sulphuric acid rather than hydrogen sulphide gas to precipitate the barium as a sulphate, no response was obtained (No. 211) . Also there was no response for the solution that resulted when the protein precipitate of No. 211 was dissolved with nitric acid and the barium precipitated as a sulphate and filtered off (No. 212). The loss of activity, if real, may have been due to either destruction or CO precipitation of the attractant by the barium ion or by the sulphuric or nitric acid. That the barium ion was not responsible is shown by the series of experiments depicted in figure 11. An alcohol extract of skipjack flesh was acidified and treated with phosphotungstic acid to precipitate the purines. Barium acetate (in one experiment) and barium chloride (in another) was used to precipitate the phosphotungstic acid and the

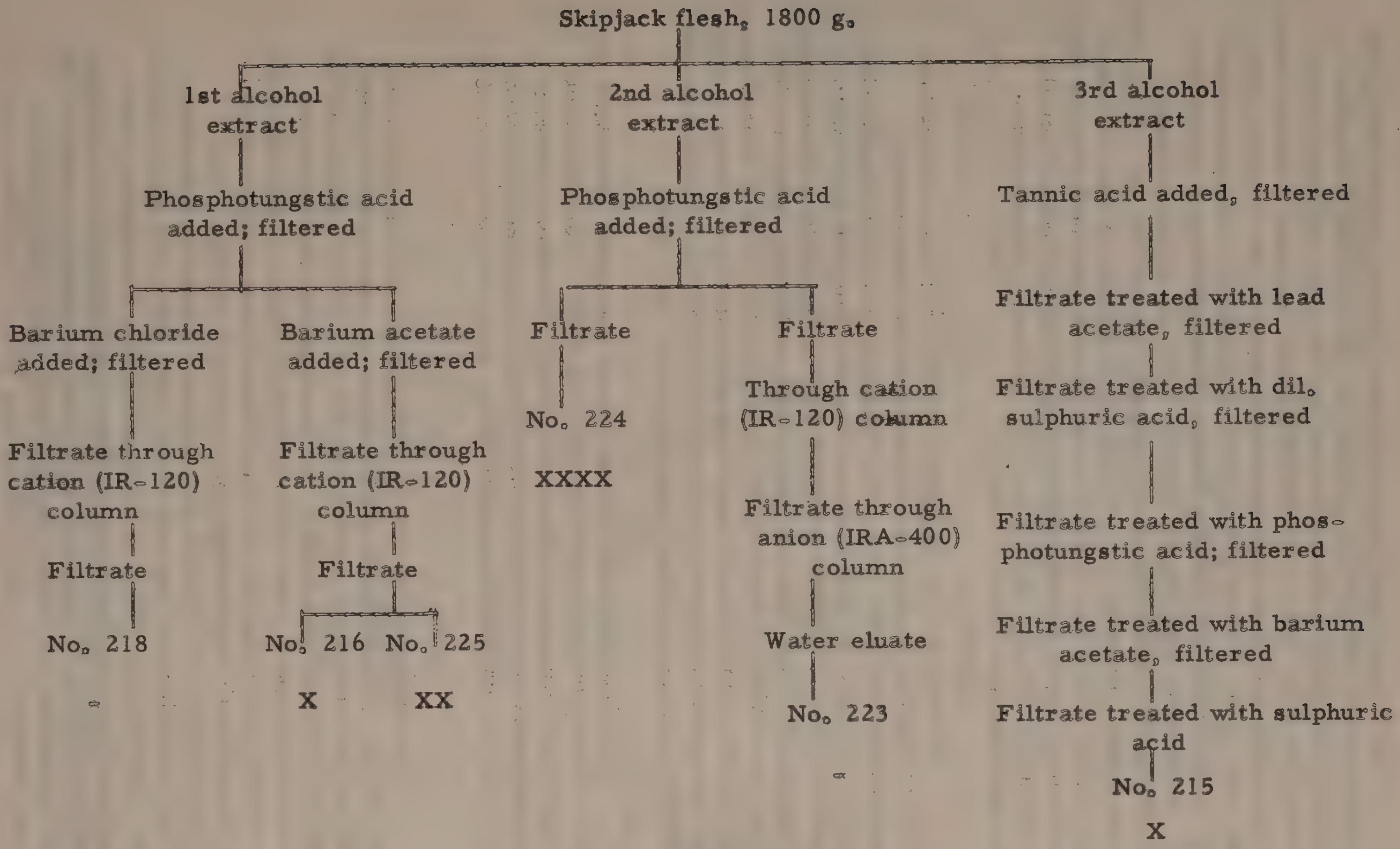

Skipjack flesh, 1800 g.
1st alcohol extract
Phosphotungstic acid added; filtered
Barium chloride added; filtered
Filtrate through cation (IR-120) column
Filtrate
No. 218
Barium acetate added; filtered
Filtrate through cation (IR-120) column
Filtrate
No. 216
X
No. 225
XX
2nd alcohol extract
Phosphotungstic acid added; filtered
Filtrate
No. 224
XXXX
Filtrate
Through cation (IR-120) column
Filtrate through anion (IRA-400) column
Water eluate
No. 223
3rd alcohol extract
Tannic acid added, filtered
Filtrate treated with lead acetate, filtered
Filtrate treated with dil. sulphuric acid, filtered
Filtrate treated with phosphotungstic acid; filtered
Filtrate treated with barium acetate, filtered
Filtrate treated with sulphuric acid
No. 215
X

Figure 11.--Fractionation of alcohol extracts of skipjack flesh: procedure and results in experiments Nos. 215, 216, 218, and 223 to 225.

proteins. There was a good response when barium acetate was used, the barium ion was removed by passage of the material through a strong cation exchange column (Amberlite IR-120), and the filtrate was tested (No. 216, 225). On the other hand, strangely enough there was no response with exactly the same treatment, but using barium chloride (No. 218). When the material treated with phosphotungstic acid was passed through a strong cation exchange column (Amberlite IR-120), the filtrate was passed through a strong anion exchange column (Amberlite IRA-400), and the eluate was tested (No. 223), there was no response, although one was expected judging by the results of previous tests. However, a weak response was obtained with the final filtrate from a series of precipitations involving the use of both the barium ion and sulphuric acid (No. 215), following the method of Suzuki et al. (1909).

Inconsistent or negative results were also obtained in attempting to repeat the various purification and fractionation techniques discussed above on a self-digested extract of ground skipjack viscera, preserved with sulphur dioxide, supplied by Hawaiian Tuna Packers, Ltd. The extract itself promoted a strong response in some experiments (No. 219), but only weak responses in others (Nos. 229, 230). It could be cooked under pressure (No. 236) or extracted with alcohol (No. 235) without loss of its attractive properties, but it could not be carried successfully through the various precipitation nor ion adsorption processes (Nos. 232, 233, 234, 237, 238).

As skipjack flesh was no longer available, attention was directed at a study of extracts of bigeye tuna flesh. Simple alcohol extracts gave good responses (Nos. 239, 240). However, weak or negative responses were obtained when the purified materials were passed through ion exchange columns (Nos. 246, 247, 248, 256, 257, 265).

The negative results in these tests may have been due either to loss or destruction of the attractant at some stage of fractionation, or they may have been due to the moribund condition of the fish prior to a January mortality. To examine the former possibility a series of experiments with extracts of bigeye flesh was undertaken as illustrated in figure 12. The filtrate from alcohol extraction was treated with lead acetate to remove the proteins, and filtered; the filtrate was treated with sodium chloride to precipitate the lead as lead chloride, and was tested (No. 266) with an excellent response. The filtrate from the sodium chloride treatment, when boiled, gave only a slight response. Some loss may have been associated with boiling after treatment with lead, although a repeat of the procedure by heating on a water bath, rather than boiling, gave a very strong response in a later experiment (No. 273). When part of

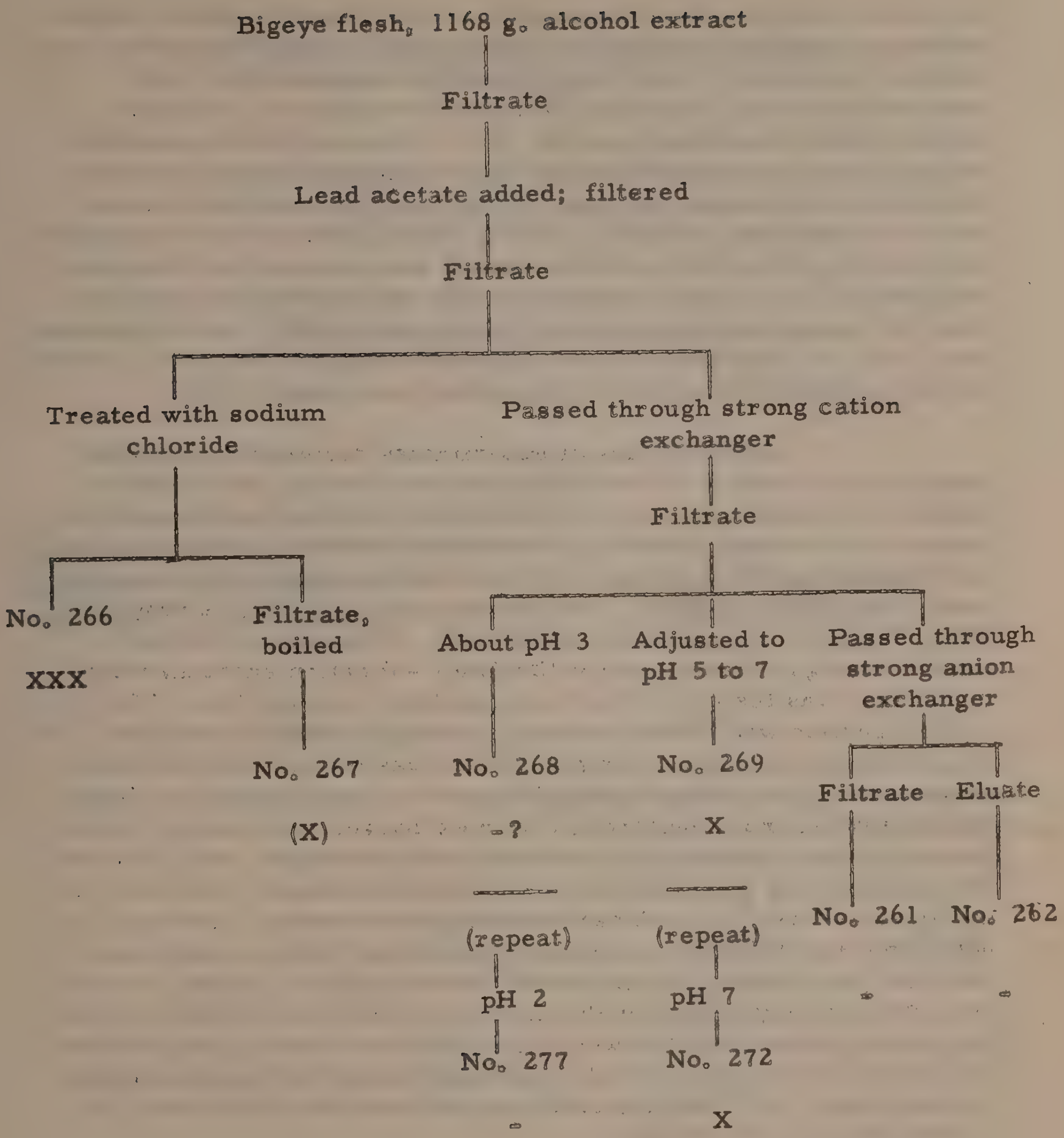

Bigeye flesh, 1168 g. alcohol extract
Filtrate
Lead acetate added; filtered
Filtrate
Treated with sodium chloride
Passed through strong cation exchanger
Filtrate
No. 266
XXX
Filtrate, boiled
No. 267
(X)
About pH 3
No. 268
?
(repeat)
pH 2
No. 277
-
Adjusted to pH 5 to 7
No. 269
X
(repeat)
pH 7
No. 272
X
Passed through strong anion exchanger
Filtrate
No. 261
-
Eluate
No. 262
-

Figure 12.--Fractionation of an alcohol extract of bigeye flesh: procedure and results in experiments Nos. 261, 262, 266 to 269, 272, and 277.

the filtrate from the lead treatment was put through a strong cation exchange column to remove the lead, and the unadsorbed portion, or filtrate, was tested, there was no positive response (No. 268). When the pH of this material was adjusted from about 3 to near neutral, there was attraction (No. 269). When a further portion of the unadsorbed material from the cation exchange column was put through a strong anion exchange column and the adsorbed (eluate) and the unadsorbed (filtrate) portions tested, there was no response to either one (Nos. 261 and 262); the pH was unknown, but was probably basic. In a repeat experiment with the unadsorbed material from the cation exchange column, adjustment to pH 7 gave a response (No. 272), but adjustment to pH 2 gave no response (No. 277). There was the possibility that loss of attraction was related to pH.

In another series of experiments designed to check the stage at which loss occurred and the effect of strong and weak exchangers, bigeye flesh after extraction with alcohol was again treated with lead acetate, filtered, treated with sodium chloride (fig. 13), and divided into aliquots such that each test contained the treated extract from 400 g. of flesh. One portion gave an excellent response (No. 273) even after heating (see above). A second portion was passed through a weakly acidic (Duolite C-3) cation exchanger and the filtrate was tested, with a weak positive response (No. 278). A third portion was passed through a strongly acidic (Amberlite IR-120) cation exchanger and the filtrate was tested, with negative results (No. 274). Fourth and fifth portions were treated as above, but the filtrate from the strong cation exchanger was passed through a strongly basic (Amberlite IRA-400) anion exchanger (No. 275) and through a weakly basic (Duolite A-3) anion exchanger (No. 276), and the eluates tested, in each case with negative results. The only noticeable reaction with materials fractionated with ion exchangers was with the filtrate from the weakly acidic column. Again, the negative results may have been due to the unresponsive condition of the fish (although they reacted well in No. 273) or to the rather extreme changes in pH which occurred in passage through the ion exchangers --from about 7 to 3 with the cation exchangers and from about 3 to 12 with the anion exchangers.

Another series, designed to check the stage at which loss of the attractive substance occurred and the effect of pH, is depicted in figure 14. Yellowfin flesh was extracted with alcohol, the filtrate was acidified with hydrochloric acid to precipitate the lead as lead chloride (rather than as sodium chloride, as before), and filtered. One portion of the filtrate gave a good reaction when tested (No. 280). A second portion of the filtrate was evaporated to dryness over a water bath and dissolved in absolute ethyl alcohol,

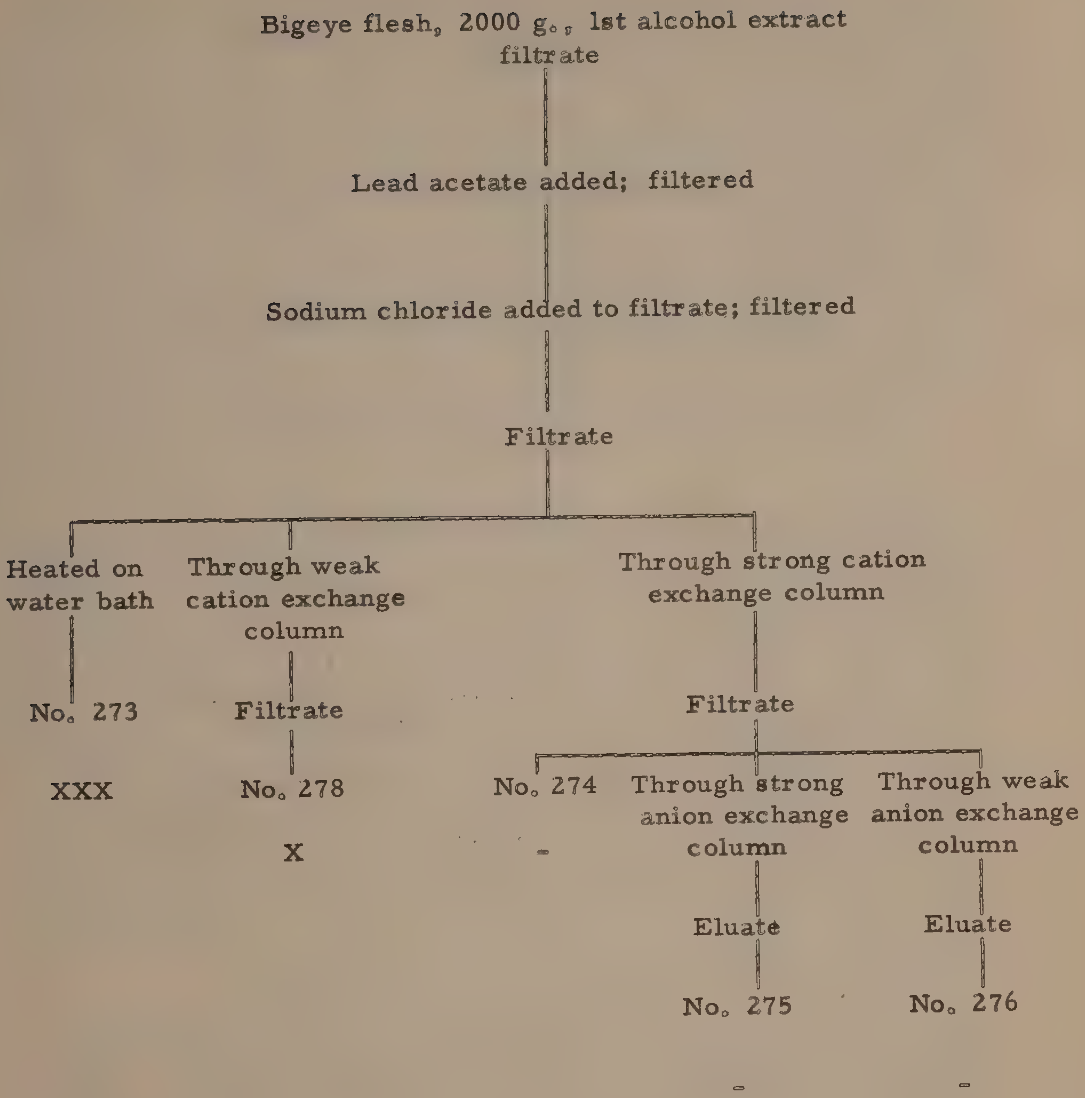

Bigeye flesh, 2000 g., 1st alcohol extract filtrate
Lead acetate added; filtered
Sodium chloride added to filtrate; filtered
Filtrate
Heated on water bath
No. 273
XXX
Through weak cation exchange column
Filtrate
No. 278
X
Through strong cation exchange column
Filtrate
No. 274
-
Through strong anion exchange column
Eluate
No. 275
-
Through weak anion exchange column
Eluate
No. 276
-

Figure 13.--Fractionation of a first alcohol extract of bigeye flesh: procedure and results in experiments Nos. 273 to 276, and 278.

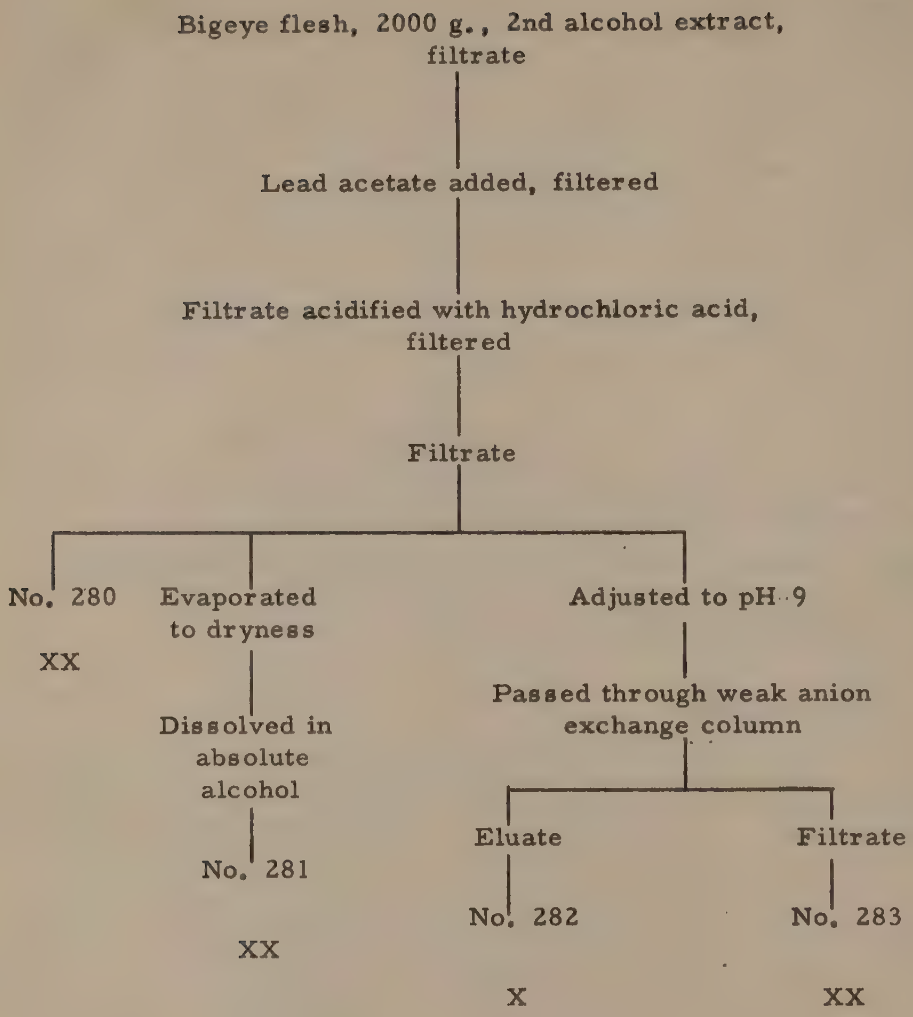

Bigeye flesh, 2000 g., 2nd alcohol extract, filtrate
Lead acetate added, filtered
Filtrate acidified with hydrochloric acid, filtered
Filtrate
No. 280
XX
Evaporated to dryness
Dissolved in absolute alcohol
No. 281
XX
Adjusted to pH 9
Passed through weak anion exchange column
Eluate
No. 282
X
Filtrate
No. 283
XX

Figure 14.--Fractionation of a second alcohol extract of bigeye flesh: procedure and results in experiments Nos. 280 to 283.

again giving a good response when tested (No. 281). A third portion was adjusted to pH 9 with ammonium hydroxide, passed through a weakly basic (Duolite A-3) anion exchange column, and the adsorbed material was eluted with weak ammonium hydroxide and tested, giving a positive but weak response (No. 282). The unadsorbed filtrate, however, gave a stronger response (No. 283). Apparently there was only partial separation of the active substance on the anion exchanger. The fact that the results were generally positive, as compared with the negative results of the previous series, is surprising as they were based on a second and presumably weaker alcohol extraction of the same material as was used previously. The main differences were the precipitation of lead with hydrochloric acid rather than sodium chloride and the elimination of the cation exchanger, neither of which should have led to the differences. They may have been caused by either aberrant fish behavior or slight differences in technique.

In a third alcohol extraction of the same tuna flesh as used previously (fig. 15), the filtrate was treated with lead acetate, filtered, the filtrate was treated with hydrochloric acid, filtered, the filtrate was adjusted to pH 7, passed through a strong (Amberlite IR-120) cation exchanger, and the filtrate of pH 2 was tested with negative results (No. 285). When the filtrate from the cation exchanger was adjusted to pH 8 with ammonium hydroxide, there was a positive response (No. 286). When the material adsorbed on the cation exchanger was eluted with weak acetic acid and tested, it gave an even stronger response (No. 287). Again, the results are puzzling. On prior tests, the attractant had not been adsorbed (to any great extent, at least) on the cation exchanger. For the material that was not adsorbed, the attractive qualities seemed to be lost at a low pH.

At this time it was suspected that the variability and inconsistency of the results might have some relationship to the pH of the materials and the length of time they were subject to extremes of pH. In passing through cation and anion exchangers, and in other treatments which were used, pH's ranging from 2 to 12 were commonly induced for varying periods of time.

Several preliminary experiments with skipjack viscera preparations (Nos. 288, 289, 290; Nos. 295, 296, 297) and bigeye flesh preparations (Nos. 292, 293, 294) in which extracts exposed to pH's of 2, 7, and 10 were compared, gave inconsistent results but suggested that the response might be less at the two extremes; the mean (observational) scores for the three sets of experiments listed above were 1.0, 1.8, and 1.5 for pH's of 2, 7, and 10, respectively.

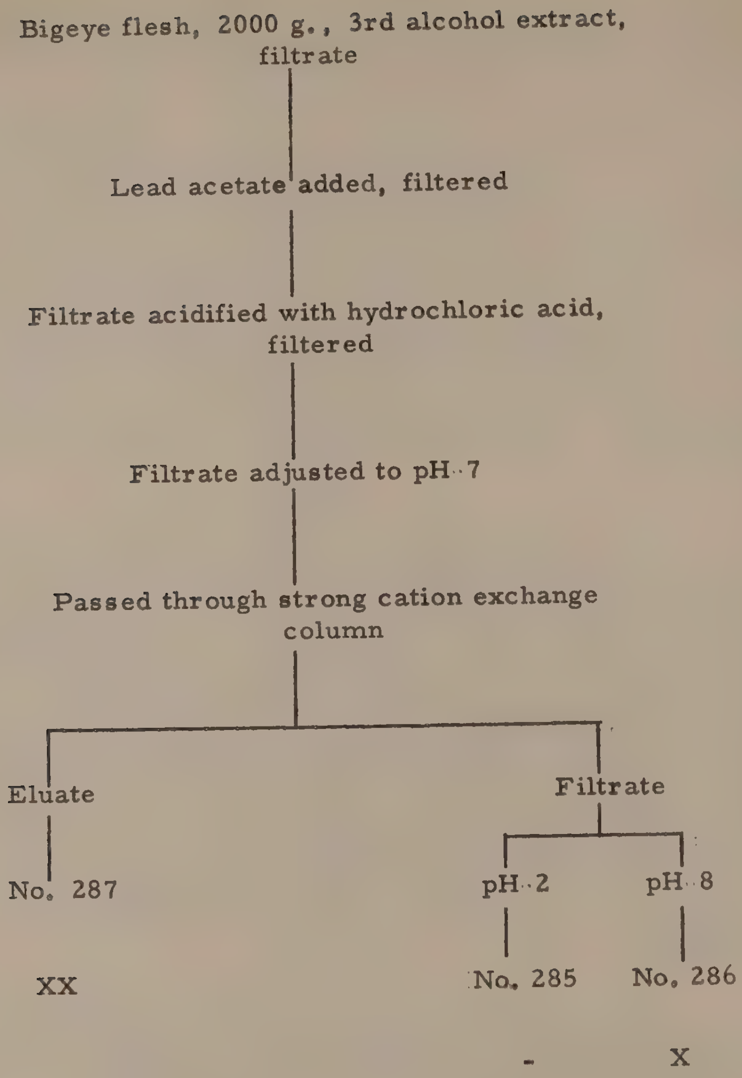

Bigeye flesh, 2000 g., 3rd alcohol extract, filtrate
Lead acetate added, filtered
Filtrate acidified with hydrochloric acid, filtered
Filtrate adjusted to pH 7
Passed through strong cation exchange column
Eluate
Filtrate
No. 287
pH 2
pH 8
XX
No. 285
No. 286
-
X

Figure 15.--Fractionation of a third alcohol extract of bigeye flesh: procedure and results in experiments Nos. 285 to 287.

A series of experiments was designed to test the hypothesis that the phosphate ion, assumed to be an integral part of the attractant, was made available at a high or low pH through hydrolysis, and that this was then precipitated (and lost) as magnesium ammonium phosphate by reaction with the seawater when the test substance was introduced. Bigeye flesh was extracted with alcohol and the filtrate was adjusted to pH 3 with hydrochloric acid to make the phosphate available for later removal. The filtrate was divided into six parts, each treated differently as shown in figure 16. Since there was a strong response to that part subjected to the most drastic method of removing the phosphate (No. 303), namely, adjusting to pH 1, boiling 15 minutes, adding 0.2 g. magnesium chloride, adjusting to pH 9, standing overnight, and then filtering and testing, the hypothesis that attraction is associated with labile or easily removed phosphate was discarded as untenable.

Finally, a series of experiments was designed to investigate the variability of the data (with only two tunny left in the pond), the effects of pH, and the effects of time lag between preparation of the material and testing. This series, conducted over a 3-week period in April 1952 (No. 313 et seq.), has already been discussed from the point of view of variability of the data. As may be calculated from table 3 (using eight complete replicates) the mean (observational) scores were 1.8, 2.1, and 1.3 at pH's of 2, 7, and 10, respectively. Although the results are suggestive of decreased response at the two extremes of pH, the differences when tested with either the observational or the quantitative data are not significant statistically. Moreover, the relative superiority of the acid and base are reversed as compared with the preliminary results given in a preceding series with skipjack viscera extract.

The preparations were made on a Saturday and were tested in two replicates on the following Tuesday or Thursday by one observer, and again in two more replicates on the following Saturday by a second observer. Thus the material tested by one observer was prepared for a shorter period of time than that tested by the second observer. The data, although incomplete for reasons discussed previously, yield 12 paired comparisons which may be segregated as follows according to time duration and pH:

	Shorter time (Observer 1)	Longer time (Observer 2)	Number of comparisons
pH 2	2.1	1.7	5
pH 7	1.4	2.1	4
pH 10	1.3	1.2	3

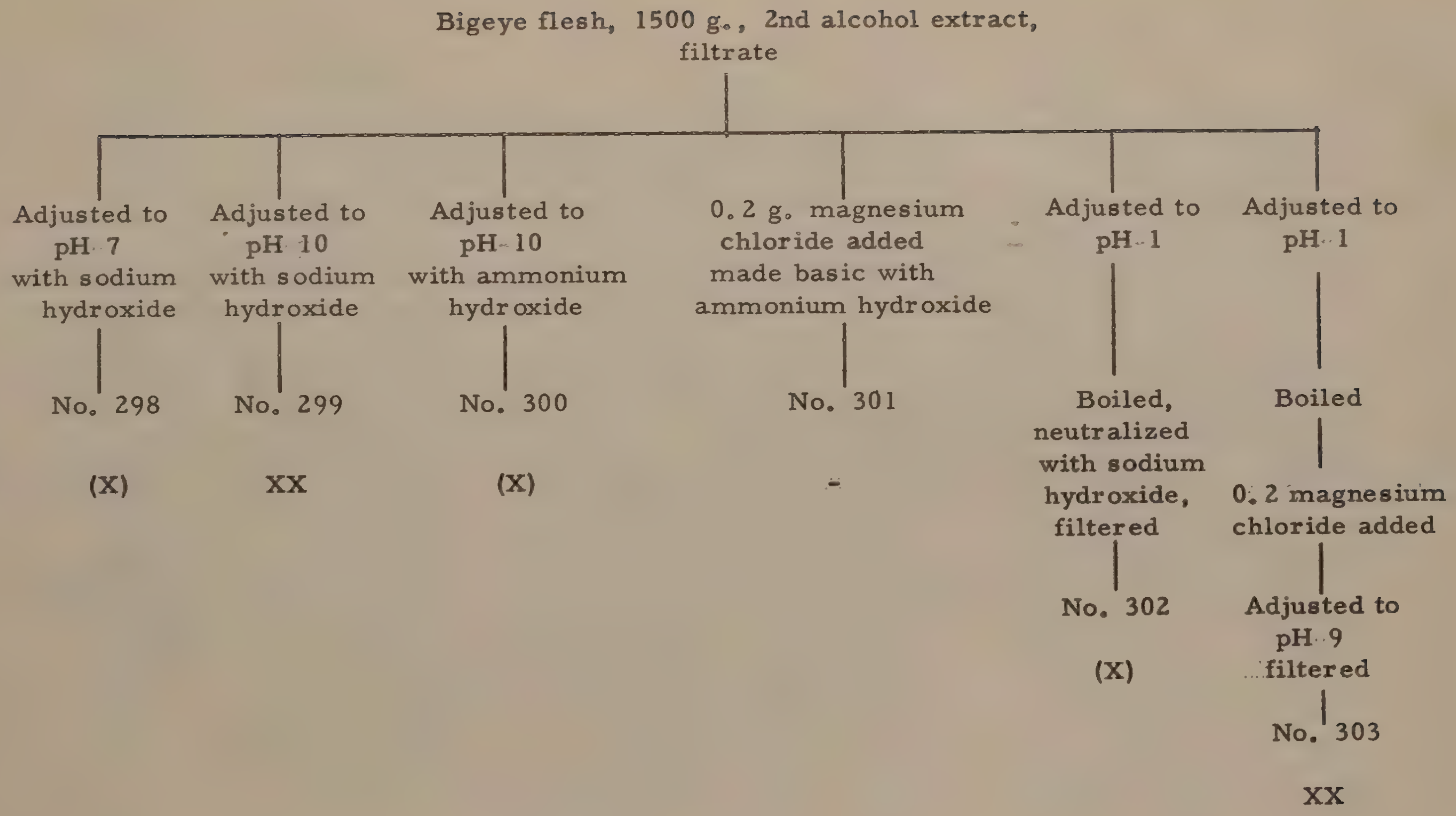

Bigeye flesh, 1500 g., 2nd alcohol extract, filtrate
Adjusted to pH 7 with sodium hydroxide
No. 298
(X)
Adjusted to pH 10 with sodium hydroxide
No. 299
XX
Adjusted to pH 10 with ammonium hydroxide
No. 300
(X)
0.2 g. magnesium chloride added made basic with ammonium hydroxide
No. 301
Adjusted to pH 1
Boiled, neutralized with sodium hydroxide, filtered
No. 302
(X)
Adjusted to pH 1
Boiled
0.2 magnesium chloride added
Adjusted to pH 9 filtered
No. 303
XX

Figure 16.--Fractionation of a second alcohol extract of bigeye flesh: procedure and results in experiments Nos. 298 to 303.

The data suggest that at pH 2 the shorter the period between preparation and testing the greater the response. Again, however, the difference is not statistically significant. Moreover, an even greater difference in the opposite direction is present at the neutral pH 7. Also, of course, any differences due to time may be confounded with possible differences between observers.

The experiment provided no proof that differences in either pH or in time lag at various pH's caused differences in reponse. Rather, it emphasized the great variability of the response --a factor which doubtless contributed mostly to the erratic results encountered after the middle of December 1952. In view of this, further attempts at isolation and identification of the attractant were abandoned.

SUMMARY AND DISCUSSION

General

The present investigation, conducted from June 1, 1952 to May 31, 1953, is a study of the response of captive tunny to extracts of fish flesh, viscera, etc. and to certain chemicals in solution or suspension.

The tunas, caught by trolling, were transported to shore and established in a small concrete tank and a large pond at the Hawaii Marine Laboratory, Coconut Island, Oahu. For the most part, they were fed strips of tuna flesh 3 or 4 times a week and, on this diet, more than tripled their weight during the course of the year. The two tunny established in the tank during the summer of 1952 survived until the following summer. The population of 13 tunny, established in the pond, was decimated in two periods of mortality during the fall and winter; two fish survived to the following summer.

Test substances were introduced into the tank or pond through a continuous stream of water supplied by an electric pump. When and where possible, precautions were taken to avoid distraction of the fish by extraneous audio or visual stimuli.

When certain test substances such as clear aqueous or alcohol extracts of tuna flesh were introduced into the tank or pond, a response was obtained. This took the form of a feeding reaction and included one or all of the following components: speeding or acceleration of the swimming rate, a return to the area of distribution of the substance, surfacing, fanning-out and eventually a breakdown of school formation, circling, splashing, and biting at incidental objects on the surface of the water.

Although a positive response was obvious to the observer, it was extremely difficult to measure quantitatively because of its complexity and also at times because of erratic behaviour of the fish. Two quantitative measures were used, namely (1) the time out of 2- (tank) or 3- (pond) minute periods spent by the fish in an "attraction" area in which the test substance was dispersed, and (2) the number of "passes" (movements of each fish in one of two directions) in the attraction area. These measurements were usually made during five control periods (before introducing a substance) and during five test periods (after introducing a substance). A roughly quantitative (observational) measure of the strength of a response in one of five categories (- to XXXX) was also recorded for each experiment. With either measure, the response to the same test substance was extremely variable in both manifestation and strength, producing apparently inconsistent results in many of the replicated experiments.

It is postulated that in tuna flesh there is present a substance (or substances), herein called the attractant, which is perceived by the tunny through its sense of smell or taste and which promotes the urge to feed.

The attractant was present in the flesh, viscera, and blood of several species of tuna and also in the flesh and blood of certain white-fleshed fish. It was not present in beef blood. It was found in tuna cannery byproducts such as viscera preparations, stickwater, and fish meal.

Some 40 chemical compounds were tested as time permitted, including certain amino acids, vitamins, aromatics, proteins, etc. In some, notably certain amino acids, vitamins, and aromatics, there appeared to be a sensing of the dissolved or suspended compound but the results could not be duplicated. In no case did the response include all of the components of a typical reaction to a tuna flesh extract.

Nature of the Attractive Substance

Much of the work was devoted to attempts at purification, fractionation, and identification of the unknown attractant. Its properties are summarized in the paragraph which follows:

The attractive substance is soluble in water and alcohol but not in petroleum ether or acetone. It is not destroyed by cold or by heat (although it may be partly precipitated on boiling an extract which contains it). It is not precipitated by sodium chloride, tannic acid, lead acetate, phosphotungstic acid, or other substances which remove proteins and purines. It will pass through a dialyzing membrane (in part, at least). It is not adsorbed (to any large extent) on activated carbon. It may be loosely adsorbed on columns of activated alumina or ion exchange resins. Of the latter, it appears to be held to a greater extent on an anion exchanger than on a cation exchanger, although the results are not consistent. It is affected slightly, if at all, by radical changes in hydrogen ion concentration. In its purest form yet attained, chemical tests showed the presence of phosphorus (but not sulphur), the amide link, and the benzene ring.

It is not yet possible to identify the attractive substance(s) from its chemical properties. It does not appear to be an amino acid, a fatty acid or lipoid, a purine, or a protein. In many of its properties it resembles Vitamin B_{12}, but this substance, while sensed by the fish, did not promote a typical positive response when tested.

Preservation of the Attractant

As sea testing of the extracts was contemplated, considerable interest centered on methods of preservation. Aqueous extracts of flesh and viscera could be kept for 2 or 3 weeks at temperatures at or just above the freezing point without excessive putrefaction and loss of activity. Aqueous extracts could be preserved indefinitely in a 2-percent solution of sulphur dioxide gas, sulphuric acid, phosphoric acid, or sodium bisulphite; apparently these chemical preservatives were not repulsive to the fish. Alcohol extracts could be kept indefinitely. Both water and alcohol extracts could be boiled to dryness, producing a dark brown, gummy residue which could be kept without deterioration for long periods of time, particularly if suspended on sodium chloride crystals; when the gummy substance was re-dissolved in water it was still attractive to the fish.

Possibility of Conditioning of the Fish

The question arises as to what extent the typical response to extracts of tuna flesh and viscera is promoted by a conditioning of the tunny to life in captivity and, particularly, to the type of food fed and the method of feeding.

The life of the tuna in the tank and pond differs greatly from that in the sea. The fishes' movements are limited by the walls and they fall into a pattern which is often precise and regular--much different from that of the open sea. Not only are their movements limited horizontally but they are also limited vertically by the shallowness of the water.

To survive in the pond or tank the tuna must become conditioned to feeding on inert, dead rather than motile, living food. After becoming conditioned to feeding on food such as strips of aku flesh, the fish appeared to have little interest in live food such as small baitfish (Stolephorus and Pranesus), which at times were present in the pond in fair abundance. On rare occasions they were observed to pursue the baitfish, which usually schooled near the seaward gates of the pond, but they would give up when the baitfish receded to a position close to the gates. They were not observed to actually capture any, and usually they ignored them. On the other hand, the tunas would almost invariably circle and snap at objects other than food which were thrown or fell accidently on the water surface (leaves, pieces of cellophane, etc.). This response was probably conditioned by the method of feeding. When a person appeared at the edge of the pond with a bucket of food, the fish would often see him and gather nearby, waiting for the food to be thrown to them. When it was thrown, they would follow its path and take it immediately it landed on the surface.

It is possible that they were conditioned to being fed at regular intervals of time (usually 4 p.m. every second day), although they would respond to the presence of both persons and food at any time except immediately after being fed.

As most of the extracts which were used were not visible to the fish, there is no doubt that the response was through the fish's sense of smell or taste rather than through its vision. However, there is the question as to whether the fish responded to skipjack flesh extracts because they were being fed pieces of skipjack, or closely-related tunas, as a regular diet. There is evidence that the response was not conditioned by the type of food which was fed.

Before and during the early experiments in the tank (to July 18, 1952) the one established tunny was fed a non-tuna diet (squid and baitfish), yet it still responded to extracts of skipjack flesh (Nos. 1, 8, 10) which it had not tasted while in captivity. Following April 25, 1953, the two tunny in the pond were fed exclusively on squid, yet almost 1 month later, May 19, 1953, they still responded to extracts prepared from skipjack viscera and yellowfin flesh (Nos. 350 to 356).

The fact that positive responses were obtained to extracts of fish other than tuna--aholehole (Nos. 49, 88, 105), jack (No. 96), and barracuda (No. 98)--while the tunny were still being fed skipjack is also evidence that the response was not conditioned by the species of fish which was being used as food. This, of course, is also illustrated by responses to extracts of tunny and yellowfin while the fish were being fed on skipjack, and responses to extracts of skipjack while the fish were being fed yellowfin or bigeye tuna.

It may be concluded that the response of the tunny in captivity is not directly conditioned to the species of food which was fed. However, there still remains the possibility that the tunny formed a mental association between feeding and the smell or taste of the dead food, which was cut up or otherwise macerated and exuded juices of similar composition to the extracts. An association such as this would not necessarily be present in the case of wild fish feeding on whole living organisms at sea. This, or some other subtile type of conditioning to life in the pond, may have contributed to the response.

The part played by conditioning can be ascertained only by testing the extracts on schools of fish at sea. Certain materials for sea testing have already been prepared and pond-tested (Nos. 264, 279, 291, 304 to 312, 350 to 356). The results of sea tests of these and other preparations will be discussed in a later report. For the present it may be stated that the preliminary sea tests were largely negative.

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PART II

RESPONSE OF TUNA TO VISUAL AND VISUAL-CHEMICAL STIMULI

BY

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During September 1952 a few experiments were conducted on a population of 12 little tunny[1] (Euthynnus yaito) established in Pond No. 5 at Coconut Island, Oahu, to determine (1) whether visual lures would promote a tropistic response, (2) whether the response was heightened when combined with chemical stimuli, i. e., an extract of tuna flesh, and (3) whether the response varied with lures of different colors. It was hoped that the results would be of interest and value in devising lures which, either alone or in combination with extracts, would assist in attracting tuna to the stern of fishing vessels at sea.

METHODS

The lures consisted of 2-inch sections of 1/2-inch rubber tubing of different colors which were suspended from a cross bar attached to the tip of a 25-foot bamboo pole, pivoted near the point of balance (fig. 17). By means of a cord, a counterweight, and a system of pulleys, two lures, one suspended from each end of the cross bar, could be momentarily dipped into the water. When an experiment was in progress the lures were lowered about once every 2 seconds.

The lure array was fastened near the base of a 20-foot observation tower and could be manipulated from the platform on top. Observations of the fish were made when they entered the 39 x 75-foot attraction area (the same area that was used in chemical stimulation studies) marked off by two pieces of cord stretching across the pond.

Note: Contribution No. 48 of the Hawaii Marine Laboratory, University of Hawaii, Honolulu, T. H.

[1] The activity of one "sick" tunny was not recorded.

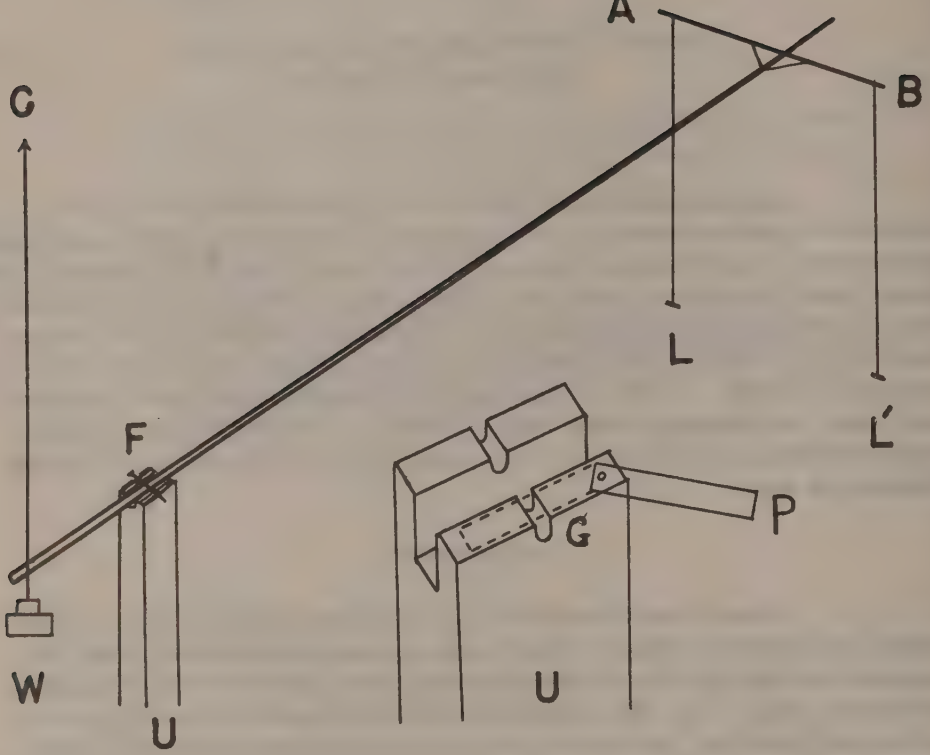

Fig. 17.--Diagram of mechanical device for lowering lures into water: AB - cross-piece; LL' - lures; U - supporting post; F - fulcrum; C - notch; P - plate to cover notch; W - weight; C - cord.

All experiments were conducted while the pump at the seaward or western end of the pond was operating. This projected a strong current of water into the first 1/10th of the pond and a weaker current into the second 1/10th, the attraction area. In some experiments, the lures only were used; in others, stock extracts of tuna flesh were introduced through the pump flow at the same time as the lures were presented. A detailed description of the pond, pump, stock extract, normal behavior of the fish, etc., is given in Part I of this report by Tester, van Weel, and Naughton, and the general arrangement for testing is shown in figure 4.

In a typical experiment the pump was switched on and the observers on top of the tower waited until the fish were behaving in a normal fashion, i. e., cruising slowly back and forth along the length of the pond in one or two schools. The activity of the fish was observed and recorded during a 15-minute control period (the data could be divided into 3-minute intervals). The lures were then dipped momentarily into the water once every 2 seconds and the activity of the fish was observed and recorded for a 15-minute experimental period. The colored lures were then reversed in position (switching left to right and right to left) and the observations were repeated. After two or more 15-minute experiments with lures, stock extract was added, the lures were dipped into the water, and observations of activity were made and recorded for another experimental period. The lures would then be switched, or changed, and the experiment repeated. In some of the early tests (9/3 and 9/5) the control and/or experimental periods were of shorter duration (9 or 12 minutes).

The behavior of the tunny, particularly during experimental conditions, was exceedingly complex. It was difficult to measure the activity with the usual devices--electrically controlled time clock, stop watch, and mechanical counter--and to record the data with pencil and paper, even when two observers were working together on top of the tower. A system of recording the behavior was worked out which consisted eventually of (1) the use of a tape recorder to give a running verbal description of the activity of the fish, and (2) the transcription of this information on the smoked paper of a kymograph drum by operating a series of levers to which styli were attached. The transcribing apparatus is illustrated in figure 18. It consists of a kymograph (F), a Franz kymograph timer (C) with two recording points, a lever (B) and stylus attached by a cord to the axle of a telephone dial (D) so that the length of the stroke on the drum is proportional to the number dialed, and a lever (A) and stylus attached by a rigid rod to a toggle key (E) which can be flipped up or down from a neutral position to make an up or down stroke on the smoked paper. The time is recorded by C, the number of fish in

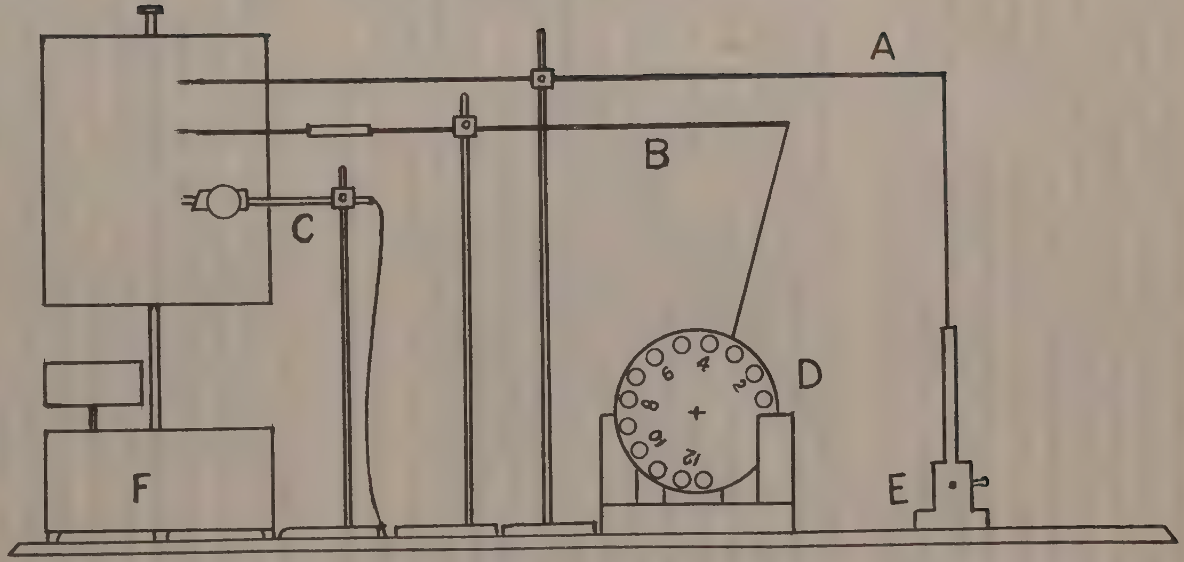

Fig. 18.--Diagram of transcribing-recording device: A - lever operated by toggle switch (E) for recording "passes"; B - lever operated by dial (D) for recording number of fish in area; C - timer; F - kymograph.

the area is recorded by B, and the number of passes at one (up) or the other (down) of the two lures is recorded by A. Typical recordings are shown in figure 19.

In addition to the above, the speed of the tunny was determined in several trials under control and experimental conditions by timing the leader of the school as it passed through the attraction area, using a stop watch.

RESPONSE UNDER CONTROL AND EXPERIMENTAL CONDITIONS

The pattern of activity of the fish was observed under control and experimental conditions and is discussed below. The activity was measured quantitatively in several different ways, each of which will be presented and discussed in the sections to follow.

Pattern of Response

During control periods the tunny, usually in one school or in two schools of unequal size, swam slowly back and forth along most of the length of the pond, looping in deeper water near the ends, or often pausing to "play" in shallower water at the ends before looping.

A kymograph record of observations during a 15-minute control period in one experiment is shown in figure 19A. It is discussed in detail to illustrate the interpretation of the kymogram. The first histogram shows that 22 seconds after the start, a school of 12 tunny entered the field from the east. After spending 24 seconds in the field, they left by the same side as they came in, and swam to the eastern end of the pond. After 165 seconds the school returned and swam through the field in 10 seconds, as shown by the second histogram. The school looped in the western 1/10th of the pond during a 9-second interval and re-entered the area from the western side. As shown by the third histogram, they sped through the field in 8 seconds. After 147 seconds the schools re-entered the area from the east, stretched out in linear formation, with the leader entering the field about 6 seconds ahead of the 12th tunny (fourth histogram). After leaving the field, the school spent 84 seconds in the western 1/10th of the pond, during which time they circled in the shallow southwestern corner near the pump. After passing through the field for a fifth time, the tunny stayed in the eastern part of the pond for a long period--about 4 minutes--before returning to pass through the area (sixth histogram). When they entered the area, 2 turned back, but 10 passed through to spend 60 seconds in the

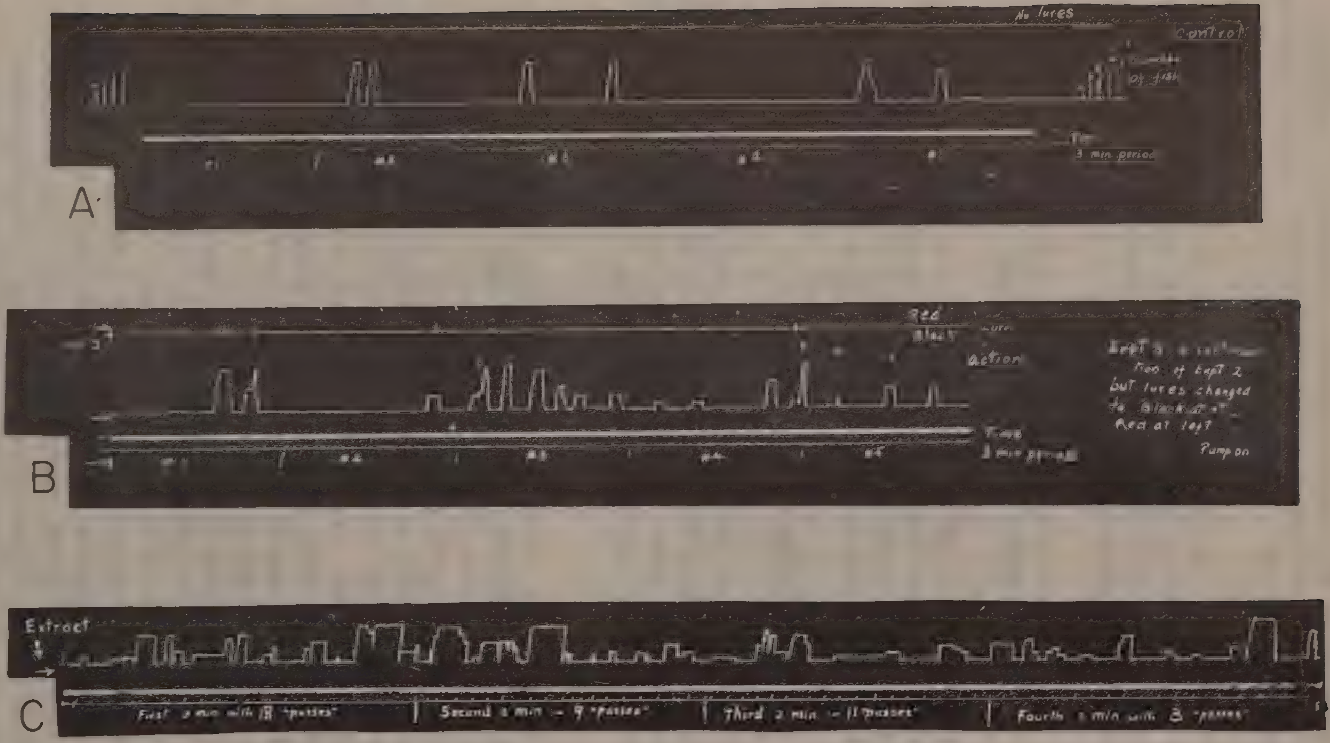

Fig. 19.--Typical kymograms: A - under control conditions; B - when stimulated by lures; C - when stimulated by lures plus extract.

western 1/10th of the pond. On turning back they sped eastward through the field in 12 seconds (seventh histogram). The two tunny which separated from the school earlier circled slowly outside the eastern border of the field, and 15 seconds after the major school left these two fish re-entered the area and swam inside for 18 seconds (eighth histogram).

When a pair of colored lures was lowered repeatedly into the water inside the attraction area, one or more tunny might be moving westerly towards the area and near enough to see the moving objects. In this case they would usually swim toward the lures and try to take them. It often happened that when one or two tunny started to bite, the others near them would become active and circle back to the lures. On the other had, if the tunny were at the far end of the pond, the lures might be lowered repeatedly for a long time without any response from the fish until they approached the attraction area. When taking after the lures, the speed of movement was not noticeably increased compared with that during the control period.

Figure 19B shows the reaction of the tunny in an experiment in which two lures, one red and the other black, were presented. They entered the field 17 times in groups of different sizes. In the third 3-minute interval, attraction and excitement is indicated by the close spacing of the histograms. The symbols "C" and "O" in the figure indicate looping and circling, respectively, inside the area. From the strokes indicating the response to the lures (upper line), it will be seen that they attempted to "take" the red lure 8 times and the black lure 6 times.

When a stock extract of tuna flesh was introduced through the stream of water at the western end of the pond the tunny would become greatly excited as soon as they sensed it. Usually the extract was propelled into the attraction area about 1 minute after its introduction. The fish would dash about with increased speed, biting at floating objects such as leaves and sticks, as well as running for the lures and fighting among themselves. There was a clearly visible feeding reaction. But after 10 to 15 minutes the response would gradually disappear and they would assume a pattern similar to that seen when lures alone were used.

In figure 19C a kymograph record of the response to lures and extract is seen. The number of passes at the lures is indicated by numbers rather than by strokes. The great excitement when extract was added is evident from the increased frequency of the histograms, together with their varied shape. The fish took the lures 18 times in the first 3-minute interval, 9 times in the second, 11 times in the third, and 3 times in the fourth.

These and other kymograph records are analyzed more extensively in the sections which follow.

School Entrances

The activity under various conditions of stimulation may be measured by the number of schools (of varying size) entering the attraction area during a 15-minute period. The results of the experiments are summarized in table 4. In this, and other tables to follow, the data for September 5 and 9 have been adjusted to a 15-minute period. The results for similar experiments conducted on the same day have been averaged.

It will be seen that on each day schools entered the attraction area more frequently (as compared with control conditions) when a pair of colored lures was dipped into the water, and still more frequently when lures were used together with extract. The grand mean number of entrances was 6.7 for controls, 14.6 for lures, and 21.6 for lures plus extract. Obviously the differences between the means are statistically significant.

Table 4.--Summary of data on the number of schools entering the attraction area under various conditions of stimulation

Condition	Date						
	9/3	9/5	9/8	9/10	9/12	9/17	Mean
Control	10	5	9	3	7	6	6.7
Lures	19.25	13	-	12.5	16	12	14.6
Lures plus extract	38.25	21.25	22.33	14.00	16.75	17	21.6

Percentage of Time in Area

The percentage or relative time spent by the fish in the attraction area is summarized in table 5 for the various conditions of stimulation. On the average the time spent in the area was 12.0

percent during control conditions, 24.5 percent when two lures were used, and 29.5 percent when the lures plus extract were used. A rough test (using "t") of significance of the difference of the paired observations (neglecting the varying intrinsic accuracy of the mean determinations for each day's experiments) indicates a significant difference between control and lures (mean difference, 13.8 percent; $P < 0.01$), but not between lures and lures plus extract (mean difference, 4.0; $P = 0.2$).

Table 5.--Summary of data on percentage time spent in the attraction area under various conditions of stimulation

Condition	Date							
	9/3	9/5	9/8	9/10	9/12	9/15	9/17	Mean
Control	9.6	6.9	20.0	4.0	14.0	15.6	14.2	12.0
Lures	27.0	17.0	-	23.5	32.7	23.8	23.1	24.5
Lures plus extract	35.0	27.8	33.7	21.3	32.7	-	26.4	29.5

Fish-seconds in Area

The summation of the product of the number of fish and time spent in the area is probably a better measure of activity than the two measures discussed above. This is equivalent to summing the areas under the histograms in the kymograph records, and may be expressed in fish-seconds per 15-minute period. The results are given for individual experiments in table 6.

In comparison with the controls, it will be observed that the number of fish-seconds is generally greater when the lures are used, and slightly greater still when the lures are combined with extract. The grand means for control, lures, and lures plus extract are respectively 114.3, 352.8, and 364.8 fish-seconds. In experiments with lures (alone) which were repeated in succession on the same day, the measure tends to fluctuate rather widely, showing neither a consistent increase nor decrease in response. In experiments with lures plus extract, the measure tends to decrease with repeated stimulation, indicating a dulling of the response. There are five comparisons of control, lures, and lures plus extract involving

Table 6.--Number of fish-seconds spent in the attraction area under various conditions of stimulation

Date	Condition		
	Control	Lures	Lures plus extract
9/3	47	(1) 253 (2) 640 (3) 101	(1) 522 (2) 107
9/5	100	(1) 683	(1) 371
9/8	120	-	(1) 657 (2) 310 (3) 345
9/10	34	(1) 646 (2) 165	(1) 380 (2) 167
9/12	135	(1) 453	(1) 504 (2) 319 (3) 292 (4) 289
9/15	124	(1) 207 (2) 168 (3) 115	-
9/17	240	(1) 80 (2) 370	(1) 635 (2) 209

initial experiments, indicated as "(1)" in table 6. These yield the following comparable means: 111.2, 423.0, and 482.4 fish-seconds, respectively. Obviously, the means for both lures alone and for lures plus extract are both significantly greater than that for controls. Although the mean for lures plus extract is greater than that for lures, the statistical significance of the difference cannot be established with the present data.

Speed of Swimming

Another measure of activity is speed of swimming. This was determined by timing the leader of the school as it passed between the two lines marking the boundary of the attraction area.

Sources of error include the effect of parallax in determining when the fish is exactly below the lines, deviation from a path exactly perpendicular to the lines, and deviation from a horizontal plane. However, variation induced by these sources of error is small compared with the variability from trial to trial. The results of observations under control and experimental conditions are summarized in table 7.

Table 7.--Summary of data on speed of swimming under various experimental conditions

Condition	Number of observations	Mean time and standard error	Mean speed (feet/second)
Control	12	18.42 ± 1.60	2.12
Lures	12	15.08 ± 0.90	2.59
Lures plus extract	20	10.15 ± 0.63	3.84

The mean speed of swimming increased beyond that of the controls when the tunny were stimulated by lures, and it increased still more when they were under the combined stimulus of lures and extract. The mean difference between control and lures is not significant statistically ($P = 0.08$). However, that between lures and lures plus extract, and also that between control and lures plus extract are both highly significant ($P < 0.01$ in each case). The increased rate of swimming of the tunny when stimulated by the extract was obvious to the observer. The actual mean swimming rate under these conditions (3.84 feet per second) is equivalent to 2.6 miles per hour. Of course, bursts of speed several times this magnitude were frequently observed.

Feeding Activity

Feeding activity may be measured by the number of passes (bitings or attempted bitings) at the lures both when used alone and when used in conjunction with extract.

Table 8 shows the mean number of passes at the lures per 15-minute period on 5 successive days. The grand means for lures and for lures plus extract are respectively 14 and 40 passes per 15-minute period. The increased feeding response under the additional stimulation of extract is apparent without further statistical analysis. The data are not suitable for isolating and testing the component of variance associated with daily variation in response.

Table 8.--Mean number of passes at lures under two experimental conditions

Date	Condition	
	Lures	Lures plus extract
9/3	26.7	51
9/5	13	20
9/10	10.5	40
9/12	6	29
9/17	14	20

RESPONSE TO LURES OF DIFFERENT COLORS

Each lure of a pair differed from its mate in color. The following combinations were tried: white-red; white-black; white-silver; red-black; and silver-black. As already explained, the positions of the lures were interchanged between experiments. The number of passes at each lure per 15-minute period was determined when lures were used alone and when they were used in combination with extract. The results are summarized in table 9.

From the table it will be observed that the white lures received either the same or, more usually, a greater number of passes than the colored lures (either tested alone or with extract) when paired with red, black, or silver lures. Similarly, the red lure seemed superior to the black in number of passes. However, none of the ratios, either individually or grouped according to similar experiments, differ significantly from a 1:1 ratio when tested with Chi-square. From the pooled data for white versus all other colored lures with which it was paired there is evidence of the superiority of white. The ratio of pooled values for white vs. color is 155:122 which, when compared with the hypothetical 138.5:138.5, yields an adjusted Chi-square of 3.7 with one degree of freedom (P = 0.06), which could be regarded as evidence for rejecting the hypothetical equality ratio. Although there is this evidence of a significantly greater number of passes at the white as compared with the colored lures, the superiority of the white lure is slight. Knowing that the tunny will make a pass at any inanimate object which appears on the surface, including not only lures but also leaves, sticks, pieces of paper, etc., the slight superiority of the white lure may perhaps be attributed to its greater visibility. There is no assurance that this superiority would be manifested in the sea, where conditions of sea water transparency and background color would be much different from those in the pond.

Table 9.--Number of passes at paired lures of different colors under two experimental conditions

Colors of paired lures	Conditions	
	Lures	Lures plus extract
White-red	(1) 5-5 (2) 10-8	(1) 31-27 (2) 7-4
White-black	(1) 8-5 (2) 4-4	(1) 10-9 (2) 12-7 (3) 7-2 (4) 21-19 (5) 6-5 (6) 15-10
White-silver	(1) 8-8	(1) 11-9
Red-black	(1) 3-3 (2) 9-9	(1) 23-20 (2) 16-13 (3) 9-6
Silver-black	(1) 11-8	(1) 12-12

SUMMARY

The activity of 12 little tunny in a large pond was observed during September 1952 under control conditions (no stimulation), when a pair of lures was dipped into the water once every 2 seconds, and when the lures were used together with stock extract of tuna flesh.

Observations were made in an "attraction area" which could be viewed from the top of a 20-foot tower. Activity was recorded verbally on a tape recorder, and later transcribed to a kymograph drum. The kymograms furnished quantitative data on activity.

As compared with control conditions, schools entered the area more frequently when stimulated with the lures, and still more frequently when stimulated with lures plus extract.

As compared with control conditions, the fish spent more time in the area when stimulated with lures, and still more time when stimulated with lures plus extract. However, the difference in relative time between the two experimental conditions was not statistically significant.

When activity was expressed as number of fish-seconds per unit time in the area, the results were similar to the foregoing. When lures and extract were used together, there was a dulling of the response with repeated testing.

The use of both lures and extract increased the rate of swimming from an average of 2.12 feet per second for controls to an average of 3.84 feet per second.

The fish made many more passes at the lures when stimulated with extract, showing a heightened feeding response.

Although, in general, the fish made more passes at white as compared with colored lures, the superiority of the white lures was slight. It may have been associated with greater visibility rather than color preference. There is no assurance that white lures would be superior to colored lures in the open sea.

APPENDIX

A summary of experiments on chemical stimulation conducted in tank (T) and pond (P) by van Weel (vW), Tester (T), or Naughton (N), over the period July 1, 1952 to May 19, 1953, with reaction classified in categories ranging from "-" to "XXXX".

Expt. No.	Date 1952	Substance and preparation	Tank or pond	Ob-server	Reaction	Remarks
1	7/1	Skipjack flesh, 150 g. extracted with 300 ml. water: centrifugate.	T	vW	XXXX	Tunny had not previously been fed skipjack flesh.
2	7/1	Same as No. 1: murky residue.	T	vW	-	Visual attraction only.
3	7/8	Ovaries, skipjack, 250 g. extracted with 500 ml. water, not centrifuged: whole extract.	T	vW	-	Cloudy material apparently repellent.
4	7/8	Testes, yellowfin, 400 g. extracted with 800 ml. water, not centrifuged: whole extract.	T	vW	-	Erratic behavior.
5	7/11	Skipjack flesh, 220 g. boiled 10' in 500 ml. water, filtrate.	T	vW	-	Erratic behavior.
6	7/11	Wahoo flesh, 170 g. extracted in 440 ml. water: centrifugate.	T	vW	-	No indication of attraction.
7	7/11	Same as No. 6: murky residue.	T	vW	-	"
8	7/14	Skipjack flesh, 225 g. extracted with 750 ml. water, not centrifuged: whole extract.	T	vW	X	Erratic behavior, but definite attraction.
9	7/14	Skipjack flesh, 282 g. boiled 10' with 600 ml. water: filtrate.	T	vW	-	

Expt. No.	Date 1952	Substance and preparation	Tank or pond	Ob- server	Reaction	Remarks
10	7/18	Skipjack flesh, 225 g. extracted with 500 ml. water: centrifugate.	T	vW	XX	Definite reaction.
11	7/18	Skipjack flesh, 282 g. boiled 10' with 600 ml. water: filtrate.	T	vW	-	
12	7/22	Skipjack flesh, 350 g. boiled 10' with 500 ml. water: filtrate	T	vW	-	Visual attraction to investigator at start.
13	7/22	Skipjack flesh, 240 g. extracted with 400 ml. water: centrifugate.	T	vW	X	Very slight attraction.
14	7/24	Yellowfin flesh, 50 g. extracted with 150 ml. water: centrifugate.	T	T	XX	Definite attraction.
15	7/24	Same as No. 14, murky residue.	T	T	XX	Definite attraction.
16	7/25	Skipjack flesh, 227 g. extracted with 500 ml. water: centrifugate.	T	vW	-	Fish had been fed 2 hours previously, slight attraction at beginning only.
17	7/28	Testes, yellowfin, 230 g. extracted with 500 ml. water, not centrifuged: whole extract.	T	vW	-	
18	7/28	Yellowfin flesh, 100 g. extracted with 200 ml. water: centrifugate treated with 3 x 50 ml. petrol ether.	T	vW	XX	

Expt. No.	Date 1952	Substance and preparation	Tank or pond	Ob- server	Reaction	Remarks
19	7/28	Ethyl alcohol, 60 ml.	T	T	-	Records lost.
20	7/28	Skipjack flesh, 203 g. extracted with 600 ml. water: centrifugate.	T	vW	XX	New fish present were distracting.
21	7/28	Skipjack flesh, 172 g. boiled 10' with 500 ml. water: filtrate.	T	vW	-	
22	7/28	Anethol, 6 ml.	T	T	(X)	Apparent attraction ?
23	7/29	Yellowfin blood, 100 ml. extracted with 500 ml. seawater, filtered through cheesecloth: filtrate.	T	T	XXX	
24	7/29	Yellowfin skin, 44 g. extracted with 300 ml. seawater: whole extract.	T	T	-	Possible visual repulsion.
25	7/29	Yellowfin liver, 82 g. extracted with 300 ml. seawater, filtered through cheesecloth: filtrate.	T	T	XX	
26	7/29	Yellowfin flesh, 100 g. extracted with 1000 ml. seawater, filtered through cheesecloth: filtrate.	T	T	X	
27	7/31	Tunny flesh, 100 g. extracted with 200 ml. dist. water, filtered through cheesecloth: filtrate.	T	T	XX	Attraction evident.

Expt. No.	Date 1952	Substance and preparation	Tank or pond	Ob-server	Reaction	Remarks
28	7/31	Tunny liver, 95 g. extracted with 200 ml. dist. water, filtered through cheesecloth: filtrate.	T	T	XXX	Attraction evident.
29	7/31	Tunny skin, 100 g. extracted with 200 ml. dist. water, filtered through cheesecloth: filtrate.	T	T	(X)	Slight attraction at first, then repulsion--visual?
30	7/31	Tunny blood, 150 cc. extracted with 300 ml. dist. water, filtered through cheesecloth: filtrate.	T	T	XX	Great excitement, but circling in attractive area only during 1st and 3rd periods.
31	8/1	dl-Phenylalanine, 2.5 g.	T	vW/T	-	
32	8/1	Arginine, 2.5 g.	T	vW/T	-	
33	8/1	l-Tyrosine, 2.5 g.	T	vW/T	-	
34	8/1	dl-Isoleucine, 2.5 g.	T	vW/T	-	
35	8/4	Gelatine, ca. 6 g.	T	T	-	
36	8/4	Eosin B, 0.6 g.	T	T	-	Slight repellent effect from this red dye.
37	8/4	Isoeugenol, 2.5 g.	T	T	-	

Expt. No.	Date 1952	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
38	8/4	Methylene blue, 0.6 g.	T	T	-	Slight repellent effect from this blue dye.
39	8/5	Skipjack flesh, 252 g. extracted with 350 ml. water, centrifuged 7/31, centrifugate dialyzed: dialyzate.	T	vW/T	XX	Feeding reaction, but not clear-cut attraction of controls.
40	8/5	Same as No. 39: residue from dialysis.	T	vW/T	(X)	Slight attraction in first period.
41	8/5	dl-Valine, 2.5 g.	T	vW	-	
42	8/5	1-Taurine, 2.5 g.	T	vW	-	
43	8/7	Skipjack blood, 125 ml.	T	vW/T	XXX	
44	8/8	l-Leucine, 2.5 g.	T	vW/T	-	
45	8/8	dl-Norleucine, 2.5 g.	T	vW/T	-	
46	8/8	Tunny blood, 110 ml. dialyzed with 500 ml. dist. water for 48 hours: dialyzate.	T	T	(X)	No excitation, positive reaction doubtful.
47	8/8	Same as No. 46: residue dialysis.	T	T	-	No noticeable reaction fish not acting normally?
48	8/11	Skipjack skin, 48 g. extracted with 150 ml. dist. water, centrifuged 1-1/2 hours: centrifugate (still cloudy).	T	T	X	Some attraction, probably not visual as "cloud" not apparent in tank.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
49	8/11	Aholehole, 70 g. extracted with 210 ml. dist. water: centrifugate.	T	T	X	
50	8/11	Skipjack flesh, 1000 ml. stock extract 1/	T	T	XXX	
51	8/12	dl-Serine, 2.5 g.	T	vW/T	X	Fish seemed to "follow" the path of solution.
52	8/12	Skipjack flesh, 306 g. extracted with 500 ml. water, centrifuged 8/7, centrifugate dialyzed: residue from dialysis.	T	vW/T	XX	
53	8/12	Same as No. 52: dialyzate.	T	vW/T	X	Increased time spent in area of attraction but no great excitement.
54	8/12	Skipjack flesh, 5000 ml. stock extract.	P	T	XXXX	Great excitement, no record kept.
55	8/14	Beef blood, whole, 200 ml.	T	T	-	Visual attraction at first, then strong repulsion.
56	8/15	dl-Serine, 2.5 g.	T	T	(X)	Possibly some attraction but no excitement.

1/ "Stock extract" was prepared by grinding 9 lb. of skipjack flesh, adding 10 gal. water and extracting in refrigerator. The clear, reddish supernatant liquid was used in testing.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
57	8/15	Skipjack flesh, 1000 ml. stock extract dialyzed with 850 ml. dist. water 8/11, and with 1100 ml. dist. water 8/12, removed 8/14; residue from dialysis.	T	T	XXX	During controls, some of material leaked in causing premature attraction.
58	8/15	Same as No. 57: dialyzate.	T	T	X	Positive but weak attraction.
59	8/18	Skipjack flesh, 1000 ml. stock extract, boiled for 1/2 hour: centrifugate.	T	T	(X)	Very slight attraction, perhaps visual to froth on water.
60	8/18	Same as No. 59: residue.	T	T	-	
61	8/18	Beef blood plasma, 280 ml.	T	T	-	
62	8/18	Albumen, 100 g.	T	T	-	
63	8/18	Skipjack flesh, 1000 ml. stock extract.	T	T	-	Possibly a slight response? Fish not responsive, throwing doubt on all 8/18 experiments.
64	8/18	Skipjack flesh, 1000 ml. stock extract.	P	T	XX	5-minute timing intervals.
65	8/18	Skipjack flesh, 500 ml. stock extract.	P	T	XXX	" " "

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
66	8/18	Skipjack flesh, 250 ml. stock extract.	P	T	XXX	Mistake in timing, first interval.
67	8/19	Skipjack flesh, 250 ml. stock extract.	P	T	XX	
68	8/19	Skipjack flesh, 1500 ml. stock extract, centrifugate ppted. with 10% HCl, centrifuged, neutralized: "non-protein fraction".	P	T	X	Slight delay in reaction.
69	8/19	Same as above, residue from second centrifuging, neutralized: "protein fraction".	P	T	XX	Good feeding reaction.
70	8/19	Skipjack blood, 50 ml.	P	T	XXX	Yellowfin also reacted strongly.
71	8/19	Anethol, 10 ml. dispersed with Tergitol.	P	T	-	Curiosity to smell in first period--licorice-like.
72	8/20	Skipjack flesh: 250 ml. stock extract.	P	T	XXX	
73	8/20	Skipjack flesh: 500 ml. stock extract, heated at 85°C for 1/2 hour.	P	T	XX	
74	8/20	Whole beef blood, 250 ml.	P	T	-	Repellent effect.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
75	8/20	Skipjack flesh, 500 ml. stock extract, heated at 69° C. for 1/2 hour, centrifuged: washed residue.	P	T	X	No great excitment,
76	8/20	Same as No. 75: centrifugate.	P	T	XX	Feeding reaction.
77	8/20	Skipjack flesh, 500 ml. stock extract, boiled 1/2 hour: filtrate.	P	T	XX	Feeding reaction, yellowfin participated.
78	8/21	Skipjack flesh, 1000 ml. stock extract, boiled 1/2 hour, centrifugate.	P	T	XX	
79	8/21	Same as No. 78: residue.	P	T	X	Very weak but positive reaction.
80	8/21	Skipjack flesh, 250 ml. stock extract.	P	T	X	Weak but positive.
81	8/21	Skipjack flesh, 250 ml. stock extract, old.	T	T	XXX	Fish in tank responsive after their rest.
82	8/21	Skipjack flesh, 250 ml. stock extract, new.	T	T	XX	"
83	8/22	Skipjack flesh, 600 ml. stock extract, boiled 15 min., centrifugate saturated with NaCl stood overnight, centrifuged: centrifugate.	P	T	XXX	Delayed reaction.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
84	8/22	Skipjack flesh, 600 ml. stock extract, boiled 15 min., centrifugate boiled one hour: centrifugate of second boiling.	P	T	XXX	Good feeding reaction.
85	8/22	Skipjack flesh, 600 ml. stock extract, boiled 15 minutes: centrifugate.	P	T	XX	Only 5 of 11 fish participating.
86	8/22	Part of No. 83: 100 ml. boiled, salted centrifugate.	T	T	XXX	Verifies No. 83.
87	8/22	Skipjack flesh, 100 ml. stock extract (putrefied).	T	T	X	Very slight reaction.
88	8/25	Same as No. 83, centrifuge residue.	P	T	-	
89	8/25	Animal Protein Factor (equivalent in growth effect to vitamin B_{12}), 50 g.	P	T	-	
90	8/25	Skipjack flesh, 1000 ml. stock extract, dialyzed 9/21 with 2 liters dist. water, changed once: dialyzate.	P	T	X	Slight reaction: feeding reaction.
91	8/25	Same as No. 90: residue after dialysis.	P	T	XX	Better reaction, fish fed heavily previous day and not too responsive; yellowfin also reacting.
92	8/25	Animal Protein Factor, 25 g.	T	T	-	Visual attraction only.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
93	8/25	Skipjack flesh, 300 ml. stock extract (putrefied).	T	T	X	Reaction apparent but weak.
94	8/26	Ulua blood, 65 ml. plus 5 cc. 4% citric acid.	P	T	X	Positive though weak.
95	8/26	Skipjack blood, 75 ml. plus 5 cc. 4% citric acid	P	T	XX	Stronger; feeding reaction.
96	8/26	Ulua flesh, 100 g. extracted with 300 ml. dist. water: centrifugate.	P	T	X	Positive but weak, lasted only short time.
97	8/26	Skipjack flesh, 250 ml. stock extract.	P	T	XX	Yellowfin also reacted, feeding reaction.
98	8/26	Barracuda flesh, 100 g. extract with 300 ml. dist. water: centrifugate.	P	T	(X)	Very slight reaction noted.
99	8/26	Aholehole whole, 250 g. extracted with 500 ml. dist. water, supernatant liquid boiled: centrifugate.	P	T	XXX	Great excitement, yellowfin reacting.
100	8/26	Same as No. 99: residue from centrifuging upper part, mostly skin, etc.	P	T	XXX	Great excitement in 2nd and 3rd periods.
101	8/28	dl-Serine, 3 g.	P	T	?	Fish showed curiosity, but no speeding up or noticeable attraction.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
102	8/28	l-Asparagine, 3g.	P	T	-	As above, sensed but no noticeable attraction. Fish erratic.
103	8/28	Arginine, 3 g.	P	T	-	As above.
104	8/28	dl-Serine, 1 g.	T	T	-	Absolutely no attraction.
105	8/28	Aholehole, whole 250 g. extracted with 500 ml. dist. water, not boiled: centrifugate.	T	T	X	Slight attraction.
106	8/28	Skipjack flesh, 250 ml. stock extract.	T	T	XX	
107	8/28	Skipjack flesh, 100 ml. of boiled, salted, stock extract, concentrated to about 1/3 original volume by boiling.	T	T	XXX	
108	8/29	dl-Serine, 3 g.	P	T	-	No reaction whatsoever.
109	8/29	Creatine, 3 g.	P	T	-	" " "
110	8/29	Nucleic acid, 3 g.	P	T	-	" " "
111	8/29	Skipjack flesh, 250 ml. stock extract.	P	T	X	Reaction positive but not strong.
112	8/29	Skipjack flesh, 3000 ml. stock extract, siphoned in over period of 48 min. to set up gradient.	P	T	XXXX	Strong and persistent reaction and attraction, fish running up gradient; time in first 1/10 of tank.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
113	9/2	Skipjack flesh, 2 liters stock extract; boiled; centrifuged; centrifugate treated with NaCl; centrifuged; centrifugate boiled to residue (plus NaCl); dissolved in sea water.	P	N	XX	Obvious reaction with feeding; tunny fighting with yellowfin.
114	9/2	Skipjack flesh, 1 liter stock extract; residue of dialysis boiled to gummy residue: portion soluble in 95% alcohol.	P	N	X	Strong in first period only.
115	9/2	Same as No. 114: portion insoluble in 95% alcohol.	P	N	(X)	Slight reaction in upper tenth of pond?
116	9/2	Same as No. 114: white crystals insoluble in 95% alcohol.	P	N	X	Definite reaction with feeding.
117	9/2	Skipjack flesh, 250 ml. stock extract.	P	N	XXX	Most vigorous reaction of the day.
118	9/4	Skipjack flesh, stock extract, 1000 ml. dialyzate boiled down to 10 ml.	P	vW	XXX	Yellowfin also reacted strongly.
119	9/4	Tuna fish meal, 10 g. boiled with 250 ml. water for 10 min.: filtrate.	P	vW	XX	
120	9/4	Tuna fish meal, 10 g. suspended in 250 ml. water, not boiled.	P	vW	XX	Perhaps not as strong a reaction as in No. 119.
121	9/4	Skipjack flesh, 2000 ml. stock extract, centrifugate salted, boiled to 10 g. residue, redissolved in water.	P	vW	X	Tide high, water murky, observation difficult.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
122	9/4	Skipjack flesh, 250 ml. stock extract: filtrate.	P	vW	XX	Tide high, water murky, observation difficult.
123	9/9	Skipjack flesh, 1000 ml. stock extract, dialyzate boiled to dryness, residue extracted with absolute alcohol.	P	vW	XX	Yellowfin also reacted.
124	9/9	Same as No. 123, alcohol insoluble portion.	P	vW	(X)	Doubtful; no reaction from yellowfin.
125	9/9	Skipjack flesh, 1000 ml. stock extract, boiled; residue (watery solution) purified by boiling with activated carbon, 1 g. gummy residue redissolved.	P	vW	X	
126	9/9	Skipjack viscera, 150 ml. juices, preserved with 2% SO_2 (H. T. P.)	P	vW	XXXX	Very strong reaction by both species.
127	9/9	Glycyl-glycine, 1 g.	P	vW	-	
128	9/9	Skipjack flesh, 250 ml. stock extract: filtrate.	P	vW	(X)	High tide; observation difficult.
129	9/11	Lecithin (animal), 2.5 g.	P	vW	-	
130	9/11	Skipjack flesh, 1000 ml. stock extract, evaporated, boiled with 5 g. activitated carbon, filtered, treated with 5 g. activated Al, evaporated to dryness; dark gum redissolved.	P	vW	X	

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
131	9/11	Ambergris, 2.5 g.	P	vW	-	
132	9/11	Pregnenolone, 1 g.	P	vW	-	
133	9/11	Skipjack flesh 1000 ml. stock extract, evaporated, boiled with 5 g. activated carbon, filtered, treated with 5 g. anion exchange resin, evaporated to light gum, redissolved.	P	vW	XXX	Strong reaction in beginning, yellowfin also participated.
134	9/11	Skipjack flesh, 1000 ml. stock extract, evaporated, boiled with 5 g. activated carbon, evaporated to dryness, treated with 5 g. cation exchange resin, evaporated to dark gum, redissolved.	P	vW	XX	Reaction not as strong as No. 133, however, pump stopped and had to be repaired so that beginning of reaction not observed well.
135	9/11	Skipjack flesh, 250 ml. stock extract.	P	vW	XXXX	Very strong reaction, with feeding manifestation.
136	9/16	Skipjack flesh extracted with equal part water, 50 ml. filtrate, frozen, thawed.	P	vW/T	XXXX	
137	9/16	Skipjack viscera extracted with equal part water, 50 ml. filtrate, frozen, thawed.	P	vW/T	XXXX	About same as No. 136, quite strong.
138	9/16	Skipjack flesh extracted with equal part water, 50 ml., boiled, frozen, thawed.	P	vW/T	X	

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
139	9/16	Skipjack viscera, extracted with equal part water, 50 ml. boiled, frozen, thawed.	P	vW/T	XXX	
140	9/16	Skipjack flesh extracted with equal part water, 50 ml. preserved at RT with 2% SO_2.	P	vW/T	XXX	
141	9/16	Skipjack viscera extracted with equal part water, 50 ml. preserved at RT with 2% SO_2.	P	vW/T	XX	Good in 1st period but died away quickly.
142	9/18	Skipjack flesh extracted with equal part water, 50-75 ml. boiled to dryness, extracted with petroleum ether (nothing removed), extracted with acetone (nothing removed), and alcohol; alcohol soluble part treated with absor. carbon and passed through cation column: portion not absorbed.	P	T	XXX	Feeding reaction.
143	9/18	Same as No. 142; portion absorbed on cation exchange resin and eluted with 0.15N NH_4OH.	P	T	-	
144	9/18	Skipjack viscera extracted with equal part water, 50 ml. treated with 2% H_2SO_4, kept at RT.	P	T	XX	Feeding reaction.
145	9/18	Same as No. 144, 50 ml. treated with 2% H_3PO_4, kept at RT.	P	T	X	
146	9/18	Same as above, 50 ml. frozen, thawed before using.	P	T	X	Feeding reaction.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
147	9/18	Skipjack flesh, 500 g. extracted with 750 ml. alcohol for 1/2 hour, 90 ml. clear, rosy-colored centrifugate.	P	T	XX	Delayed reaction.
148	9/23	Skipjack flesh, as above, extracted for 2 days with alcohol, 340 g. residue from centrifuging washed with alcohol, washed with water, extracted with 240 g. water since 9/19: centrifugate.	P	T	XXX	Feeding reaction.
149	9/23	Skipjack flesh extracted with equal parts alcohol, 100 ml. centrifugate passed through activated alumina: portion not absorbed.	P	T	XX	Feeding reaction.
150	9/23	Same as No. 149: portion absorbed on activated alumina, eluted with water.	P	T	XXX	Slightly better than No. 149; feeding reaction.
151	9/23	Skipjack flesh extracted with equal parts alcohol, 100 ml. centrifugate passed through zeolite: portion not absorbed.	P	T	XX	Feeding reaction.
152	9/23	Same as No. 151: portion absorbed on zeolite eluted with water.	P	T	XX	Slightly weaker than No. 156; feeding reaction.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
153	9/25	Skipjack flesh, 100 ml. alcohol extract adsorbed on activated charcoal: portion adsorbed, eluted with water, clear.	T	T	X	Reaction at first only.
154	9/25	Same as No. 153: portion not adsorbed (yellowish alcohol solution).	T	T	XXX	Feeding reaction.
155	9/25	Skipjack flesh, 400 ml. alcohol extract from No. 147; centrifuged; centrifugate ev. to dryness at R. T.; brown gum redissolved in 95% alcohol; passed through activated aluminum column: filtrate evap. to dryness and brown gum redissolved in water.	T	T	X	
156	9/25	Same as No. 155: eluate evap. to dryness and redissolved in water.	T	T	XXX	Most of fish did not enter attraction area until 3rd period; great feeding reaction.
157	9/25	Methionine, 0.5 g.	T	T	-	Fish exhibit curiosity?
158	9/25	Alpha Ionone, 2 ml.	T	T	-	

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
159	9/30	Skipjack flesh, 600 g., extracted with 1000 ml. alcohol; 100 ml. treated with activated charcoal till clear, and passed through charcoal column; eluted with acetone; ca. 10 mg. small white crystals in eluate dissolved in water.	P	T	X	Weak, no feeding reaction.
160	9/30	Same as No. 159: white ppte. in alcohol residue, not adsorbed on charcoal, dissolved in water.	P	T	-	No obvious reaction.
161	9/30	Same as No. 159: portion not adsorbed on charcoal (minus white ppte. of No. 160).	P	T	XX	Feeding reaction.
162	9/30	Alcohol extract (No. 159), 100 ml., adsorbed on activated alumina: portion not adsorbed.	P	T	XX	Slightly better reaction than No. 161.
163	10/2	Skipjack flesh, 200 g. extracted once with 500 ml. alcohol (48 hr.); filtered: reddish clear filtrate.	P	T	XXXX	Great excitement, feeding reaction lasting 15 min.
164	10/2	Same as No. 163; residue extracted 2nd time with 500 ml. alcohol; filtered; residue extracted third time with 700 ml. water; filtered: clear colorless filtrate.	P	T	XX	Fish didn't enter field until end of 2nd period; then very strong feeding reaction.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
165	10/2	Same as No. 162: yellowish, slightly cloudy portion adsorbed on alumina and eluted.	P	T	XXX	Great excitement and feeding reaction.
166	10/7	Vitamin B_{12}, 5 mg. dissolved in water, reddish color.	P	T	-	Possibly sense material, but no noticeable reaction.
167	10/7	Skipjack flesh, 50 g., extracted with 50 ml. alcohol; adsorbed on charcoal: white crystals in eluate re-dissolved in water.	P	T	-	Fish surfaced, but no other noticeable reaction.
168	10/7	Pineapple juice, 160 ml.	P	T	- ?	Fish sensed it; surfaced and turned back; no feeding.
169	10/7	Skipjack flesh, 600 g., extracted twice with 600 ml. alcohol; extracted a third time with water: 500 ml. centrifugate from water extraction.	P	T	XX	Fish didn't enter field until 2nd period; some feeding reaction but not as much as in No. 164.
170	10/9	Skipjack flesh, 100 g., extracted twice with alcohol; further extracted with alcohol for 14 hours in Soxhlet; residue extracted 12 hours with 200 ml. dist. water; centrifuged: clear colorless centrifugate.	P	T	(X)	Very slight reaction, no feeding.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
171	10/9	Alcohol extract from No. 170, adsorbed on charcoal; eluted with acetone; 20 mg. white needle-like crystals dissolved in water.	P	T	(X)	Slight sensing? No surfacing, no feeding.
172	10/9	"Alamask" (DuPont aromatic R-200.611), 2 ml. dispersed with Tergitol and emulsified in water.	P	T	-	
173	10/9	Skipjack flesh, stock solution, 250 ml. (old, deteriorated, weakened by successive freezing and removal of unfrozen solution).	P	T	X	Positive reaction in first and second period, but not thereafter.
174	10/11	"Slik", 10 ml.; (commercial fish attractant).	P	vW	-	Has cod liver oil smell. Fish noticed it but not noticeably attracted.
175	10/11	Skipjack flesh, 100 g., extracted with alcohol in Soxhlet; extracted with petrol ether; evaporated; residue dissolved in abs. alcohol and dispersed in water with tergitol.	P	vW	X	Slight attraction, no feeding reaction, speed decreased after 10 min.
176	10/11	Acetyl tryptophane, 1.5 g. dissolved in water.	P	vW	-	

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
177	10/16	Skipjack flesh, 200 g., extracted with alcohol; evap. to dryness; fatty substances dissolved in pet. ether; pet. ether evaporated; residue taken up with abs. alcohol, dispersed in water with Tergitol: white emulsion.	P	T	X	Definite speeding up and surfacing, but rather weak reaction.
178	10/16	Skipjack flesh, 250 g., extracted with alcohol; passed through charcoal column; evap. to dryness and extracted with pet. ether; passed through Duolite C-3 Cation exchange resin: clear colorless portion not adsorbed on cation resin.	T	T	X	Slight speeding up noticed. Experiment disturbed by rain squall.
179	10/16	Same as No. 178, but passed through Duolite A-3 Anion exchange resin: clear, yellowish portion not adsorbed on anion resin.	P	T	X	Good reaction for first period, but died off quickly. Rainstorn disturbed experiment.
180	10/21	Skipjack flesh, 340 g. extracted for 9 days with 340 ml. alcohol; centrifugate.	P	T	XX	Reaction lasted for 3 periods, surfacing and feeding.
181	10/21	Same as No. 178: portion adsorbed on cation exchange resin and eluted with 5% H_2SO_4: colorless eluate.	P	T	(X)	Sensed material but very slight reaction, if any.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
182	10/21	Same as No. 179: portion adsorbed on anion exchange resin and eluted with 5% NaOH: yellowish eluate.	P	T	XX	Good reaction, including surfacing and feeding.
183	10/21	Skipjack flesh, 250 g. extracted with alcohol; charcoal treated; fat extracted; evap. to dryness in vacuum: portion of residue insoluble in 95% alcohol but soluble in water, purines removed as Ag salts: yellowish sol.	P	T	XX	Good reaction including surfacing and feeding.
184	10/21	Same as No. 183: portion of residue soluble in 95% alcohol; purines removed as Ag salts: yellowish solution.	P	T	X	An obvious speeding-up in first three periods.
185	10/25	Skipjack flesh, 700 g., extracted with alcohol, conc. under vacuum; fat out with pet. ether, ether removed under vacuum; passed over charcoal; adsorbed on anion exchange resin Duolite A-3; eluted with 10% NH_4OH: 1st portion of eluate.	P	vW	XX	*Abudefduf* also left coral and reacted.
186	10/25	Same as No. 185: 2nd portion of eluate.	P	vW	X	Tuna swam slowly, no *Abudefduf* reaction.
187	10/25	Same as No. 185: 3rd portion of eluate.	P	vW	-	Seemed to note substance only during 1st minute.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
188	10/25	Trimethylamine oxide, 1.5 g. in water.	P	vW	-	
189	10/25	Peptone "I" (Nutr. Biochem.), 1.5 g. in water.	P	vW	-	
190	10/25	l-Histidine monohydrochloride, 1.5 g. in water.	P	vW	-	
191	10/25	l-Glutamic acid, 1.5 g. in water.	P	vW	-	
192	10/28	Acetylcholine chloride, 100 mg. in water.	P	T	-	Sensed material but no surfacing or feeding reaction.
193	10/28	Skipjack flesh, 350 g., extracted with alcohol; fat out with pet. ether; through charcoal column; through anion exchange column; portion held on column and eluted with NH_4OH; evaporated in vacuum; residue redissolved in water and nitrogen compounds ppted. with phosphotungstic acid: filtrate.	P	T	XX	Good reaction with surfacing and feeding.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
194	10/28	Skipjack flesh, 700 g., second alcohol extraction; through charcoal column; through anion exchange column; portion eluted from column with water: whitish liquid.	P	T	XX	Fish late in entering area, but then showed good reaction, with feeding.
195	10/28	Same as No. 194: portion eluted from column with 95% alcohol.	P	T	-	No reaction at any time.
196	11/8	Skipjack flesh, extracted with alcohol; treated with lead acetate; filtered; fat removed from filtrate with pet. ether; lead removed with H_2S, and H_2S removed in vacuum; adsorbed on anion resin and eluted with 5% NH_4OH: eluate neutralized with HCl.	P	vW	-	No noticeable reaction; visibility poor.
197	11/8	Same as No. 196 to removal of H_2S: filtrate.	P	vW	XXXX	Tuna showed surfacing and feeding reaction; also Abudefduf; visibility poor.
198	11/8	Histamine diphosphate, 8 mg., free base liberated with NH_4OH.	P	vW	-	Abudefduf may have showed a slight reaction; visibility poor.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
199	11/18	Skipjack flesh, 80 g., extracted with water one month previously: held in reefer.	P2/	T	XXX	Good reaction with surfacing.
200	11/18	Same as No. 196, i.e. leaded, de-leaded, fat removed, passed through anion column twice; filtrate from anion column.	P2/	T	-	No reaction, except perhaps a slight sensing of material?
201	11/18	Same as No. 196; water eluate from No. 200 evaporated to dryness and treated with abs. alcohol: residue soluble in alcohol.	P2/	T	XX	Fair reaction with surfacing and feeding.
202	11/18	Same as No. 201: residue insoluble in alcohol but soluble in water.	P2/	T	-?	May be slight attraction?
203	11/18	Skipjack flesh extracted with water, same as No. 199.	P2/	T	XXX	Good reaction.
204	11/22	Same as No. 201: weak NH_4OH eluate evaporated to dryness, treated with abs. alcohol: residue soluble in alcohol.	P2/	vW	-	No reaction.
205	11/22	Same as No. 204: residue insoluble in alcohol but soluble in water.	P2/	vW	-	
206	11/22	Same as No. 201: eluate at pH 3-4, neutralized.	P2/	vW		

2/ Material thrown from tower; pump not working.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
207	11/22	Skipjack flesh, extracted with water, ca. 100 ml.	P[2/]	vW	XXXX	Good reaction.
208	12/6	Same as No. 196: first portion of water eluate from anion column, basic in nature.	P	vW	X	Swimming speed increased, no feeding reaction.
209	12/6	Same as No. 208: third portion of water eluate from anion column, still basic in nature.	P	vW	-	
210	12/6	Same as No. 208: fourth portion of water eluate from anion column, starting to become acidic.	P	vW	-	
211	12/9	Skipjack flesh, extracted with alcohol; treated with barium acetate; filtered; filtrate treated with H_2SO_4 to ppte. $BaSO_4$ and this left in suspension: filtrate.	P	T	-?	Visibility poor; no apparent reaction, although fish did not enter field until after expt. was over.
212	12/9	Same as No. 211: residue treated with NHO_3 and barium ppted. as $BaSO_4$: filtrate.	P	T	-	Visibility ok.
213	12/9	Same as No. 196, but new anion exchanger (Amberlite IRA-400) used: first water eluate.	P	T	XX	Surfacing and feeding reactions.
214	12/9	Same as No. 213: second water eluate.	P	T	-	May have been a slight sensing.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
215	12/9	Skipjack flesh, 1800 g. third alcohol extract; treated with tannic acid (protein out); treated with $PbAc_2$ (protein and tannic acid out); treated with H_2SO_4 (Pb out); treated with phosphotungstic acid (purines out); treated with Ba (phosphotungstic acid out); treated with SO_4 (Ba out).	P	T	X	Very weak, if any, reaction.
216	12/9	Skipjack flesh, 1800 g. first alcohol extract, 100 ml.; treated with phosphotungstic acid; filtered; phosphotungstic acid removed with barium acetate; passed through cation column (Amberlite IR-120) to remove barium: filtrate from column.	P	T	X	Very weak. Reaction about the same as No. 215.
217	12/11	Fresh tuna stickwater from H. T. P. (high oil content): 200 ml.	P	T	XXX	Reaction good; feeding and surfacing.
218	12/11	Same as No. 216, except barium chloride used: filtrate from column, neutralized.	P	T	-	Material introduced too soon by accident, but no reaction.
219	12/11	Skipjack whole ground viscera (except gonads), preserved in 2% SO_2, self-digested; prepared 9/25/52 by H. T. P.: 200 ml. brown mixture from can.	P	T	XX	Fair reaction with feeding and surfacing.
220	12/11	Skipjack whole viscera, steamed at 20 lb. press.; preserved in 3% PO_4 in bottle; prepared 5/26/52 by H. T. P.; yellowish supernatant liquid, 125 ml.	P	T	XXX	Good reaction which was renewed when pipe was flushed after expt.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
221	12/11	Skipjack whole ground viscera, preserved in 3% SO_2 in bottle; prepared 5/26/52 by H. T. P.; yellowish supernatant liquid, 125 ml.	P	T	XXXX	Surfacing, speeding up, best feeding reaction yet observed.
222	12/11	Same as No. 217: fresh tuna stickwater, 200 cc. mixed with fluorescein dye.	P	T	XXX	Good reaction which could be traced with dye.
223	12/13	Skipjack flesh, 1800 g., second alcohol extract, treated with phosphotungstic acid; filtered; filtrate through cation (Amberlite IR-120) column; filtrate through anion (Amberlite IRA-400) column: first water eluate.	P	vW	-	May have sensed material at beginning.
224	12/13	Same as No. 223, but carried only through phosphotungstic acid precipitation: filtrate.	P	vW	XXXX	Tunny followed material when it drifted out through gates; other fish also reacted.
225	12/13	Same as No. 216: filtrate from cation co column neutralized.	P	vW	XX	Although reaction not vigorous it was positive.
226	12/16	Skipjack viscera self-digested and preserved in 2% SO_2 (same as No. 219); 200 ml. extract plus 200 ml. 95% alcohol adjusted to pH-9 with NH_4OH; filtered; centrifuged to remove crystals; centrifugate.	P	T	X	A poor reaction, no surfacing or feeding (cf. No. 219).

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
227	12/16	Same as No. 226: crystals, residue from centrifuging, dissolved in water.	P	T	-	
228	12/16	Skipjack viscera (same as No. 219),200 ml. water added; boiled; 200 ml. water and 1100 ml. 95% alcohol added; coagulation; filtered: filtrate, pH 7.	P	T	-	No noticeable reaction?
229	12/16	Same as No. 219.	P	T	(X)	A slight reaction when fish finally entered field in 4th period.
230	12/16	Same as No. 219 (repeat of No. 229).	P	T	X	Some reaction, but no feeding.
231	12/16	Furfuryl mercaptan 10% (Du Pont Aromatics No. 2295), dispersed in water with Tergitol, 1.5 ml.	P	T	?	The material was sensed; fish surfaced, and kept returning to area. No feeding reaction noted.
232	12/27	Skipjack viscera prep. (same as No. 219), 200 ml., treated as in No. 228; filtrate adjusted to pH 2 with H_2SO_4; phosphotungstic acid added; filtered; filtrate treated with $Pb(Ac)_2$; filtered; filtrate passed through strong cation exchanger (Amberlite IR-120): unadsorbed portion.	P	vW	(X)	Slightly excited, milling around inlet for short period; very weak reaction.

Expt. No.	Date 1952	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
233	12/27	Skipjack viscera prep. (same as No. 219), 200 ml.; 400 ml. 95% alc. added; stood 1/2 hr., filtered; phosphotungstic acid added to filtrate after adjusted to pH 2 with HCl; filtered; $Pb(Ac)_2$ added to filtrate; filtered; filtrate passed through strong cation exchanger (Amberlite IR-120); adjusted pH unadsorbed portion to pH 4; passed through strong anion exchanger (Amberlite IRA-400); unadsorbed portion.	P	vW	-	No reaction.
234	12/27	Skipjack viscera prep. (same as No. 219); treated as in No. 233; adsorbed portion from anion column.	P	vW	-	No reaction.
235	12/27	Skipjack viscera prep. (same as No. 219), 400 ml.; 1000 ml. 95% alc. added; stood 1/2 hr., filtered: filtrate.	P	vW	XXX	Strong reaction with feeding.
236	12/27	Skipjack viscera prep. (same as No. 219), 400 ml.; cooked under pressure for 1/2 hr.; filtered: filtrate.	P	vW	X	Positive but weak attraction; no feeding reaction.
237	12/30	Skipjack viscera prep. (same as No. 219); treated same as No. 233: portion unadsorbed on anion column.	P	T	-	No reaction.
238	12/30	Skipjack viscera prep. (same as No. 219); treated same as No. 234: portion adsorbed on anion column.	P	T	-	No reaction.

Expt. No.	Date 1952/53	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
239	12/30	Bigeye flesh, 100 g. plus 140 ml. water extracted, filtered: filtrate.	P	T	XX	Speeding, surfacing and feeding; visibility poor.
240	12/30	Bigeye flesh, 100 g. plus 140 ml. water, cooked under pressure 1/2 hr., filtered: filtrate.	P	T	XX	About same as No. 239.
241	12/30	Furfuryl mercaptan, 1.0 ml., dispersed with Tergitol in water.	P	T	(X)	Surfacing, speeding but no feeding, attraction?
242	1/6	Adenosine, 1.0 g., dissolved in water just prior to testing.	P	T	-	No reaction.
243	1/6	Adenosine triphosphate, disodium salt, 95% 0.1 g., dissolved in water just prior to testing.	P	T	(X)	No speeding or feeding, but continuous turning back, a sensing of material?
244	1/6	Adenylic acid (muscle), 0.1 g., dissolved water (not very soluble).	P	T	-	No reaction.
245	1/6	Adenosine diphosphate, barium salt, 0.1 g., dissolved in 0.1N HCl and Ba ppted. with 6N H_2SO_4 just prior to testing.	P	T	(X)	Speeding and turning back; a sensing of material?
246	1/6	Bigeye flesh, alcohol extract, leaded and de-leaded through anion exchanger; adsorbed portion eluted and evap. to dryness; re-dissolved in abs. alc. and fractionated on alcohol anion column; adsorbed portion eluted with 250 ml. water; 10 ml. fractions collected; fractions 1-6.	P	T	(X)	Turning back, but no surfacing or feeding; visibility poor.

Expt. No.	Date 1955	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
247	1/13	Same as No. 246; fractions 7-13 incl.	P	T	?	Fish came into field in 1st period but then stayed down-stream for 3 periods Appeared to notice material when in field in 5th period.
248	1/13	Same as No. 246; fractions 14-26 incl.	P	T	-	No reaction.
249	1/13	Coumarin, 3 g. (DuPont Aromatics R. 1697), dissolved in water.	P	T	-	No reaction.
250	1/13	Methyl anthranilate, 2 ml. (DuPont Aromatics R. 1581), dispersed with Tergitol in water.	P	T	-	No reaction.
251	1/13	Phenyl acetic acid, 2 g. (DuPont Aromatics R. 7618) dissolved in water.	P	T	-	No reaction.
252	1/13	Bigeye flesh, 125 g. extracted with water; filtered; filtrate.	P	T	XX	Surfacing speeding, milling, and feeding reaction.
253	1/13	Meat flavor, 1 ml. (SA. 6321), dissolved in water.	P	T	(X)	Seemed to sense material; kept turning back, feeding reaction.
254	1/17	Adenosine triphosphate, disodium salt (same as No. 243).	P	vW	-	No reaction.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
255	1/17	Adenosine diphosphate, barium salt (same as No. 245).	P	vW	-	No reaction.
256	1/17	Bigeye flesh, 1800 g. extracted with 1000 ml. 95% alcohol; filtered; filtrate treated with $Pb(Ac)_2$ and Pb removed on strong cation exchanger; unadsorbed portion adjusted to pH-4 with NH_4OH and passed through strong anion exchanger; adsorbed portion eluted with water, evaporated, re-dissolved in abs. alc.; heated to boiling; charcoal added and filtered; 1/6 of filtrate (equiv. to 200 g. flesh).	P	vW	-	No reaction.
257	1/17	Bigeye flesh, 1000 g. extracted with 1000 ml. alcohol, $Pb(Ac)_2$ added; filtered filtrate put through cation exchanger; unadsorbed portion filtered to remove ppte.; filtrate through anion exchanger and eluted with water; 1/2 adsorbed portion (equiv. to 500 g. flesh).	P	vW	(X)	A little excitement at beginning but no feeding nor attraction.
258	1/20	Skipjack viscera prep. (HTP)[3], pepsin digested, preserved in 2% $NaHSO_3$, 200 ml.	P	T	-	No reaction.
259	1/20	Bigeye flesh, 125 g., extracted with water, filtered: filtrate.	P	T	(XX)	Characteristic reaction with feeding.

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[3] Hawaiian Tuna Packers, Ltd.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
260	1/20	Skipjack viscera prep. (HTP) pepsin digested, 60 ml. (same as No. 258)	P	T	(X)	Possibly a slight reaction?
261	1/20	Same as No. 268 and 269; remainder of unadsorbed portion from cation column put through strong anion exchanger: unadsorbed portion equivalent to 200 g. flesh.	P	T	-	No reaction.
262	1/20	Same as No. 261: adsorbed portion on anion column eluted with 200 ml. water and tested, equivalent to 200 g. flesh.	P	T	-	No reaction or very slight.
263	1/22	Skipjack viscera prep. (HTP), pepsin digested 200 ml. (same as No. 258).	P	T	-	No reaction.
264	1/22	Skipjack viscera prep. (HTP), steam cooked (1 hr./10 lb.) filtered; clear yellow filtrate preserved in 2% $NaHSO_3$: 200 ml. tested.	P	T	XX	Very strong feeding reaction.
265	1/22	Same as No. 256, except alcohol evaporated in vacuum desicator: crystals and sludge re-dissolved and tested (equiv. to 700 g. flesh).	P	T	-	No reaction, but fish erratic in behavior.
266	1/22	Bigeye flesh, 1168 g. extracted with 95% alcohol and filtered; filtrate treated with $Pb(Ac)_2$; filtered; filtrate equiv. to 200 g. flesh treated with NaCl (ppte. not removed) and tested.	P	T	XXX	An excellent reaction, with feeding.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
267	1/22	Same as No. 266; except filtrate equivalent to 200 g. flesh treated with NaCl, filtered, and filtrate heated to boiling for 30 min.	P	T	(X)	Possibly a weak reaction.
268	1/22	Same as No. 266; remainder of filtrate put through strong cation exchanger; unadsorbed portion equivalent to 200 g. flesh tested (pH not adjusted).	P	T	?	No reaction except perhaps in first two periods when first turned back.
269	1/22	Same as No. 268, except unadsorbed portion was adjusted to pH-5 to 7 with dil. NH_4OH, equiv. to 200 g. flesh.	P	T	X	A positive but weak reaction; no feeding.
270	1/30	Adenosine diphosphate, barium salt (same as No. 240).	P	T	-	No reaction; pump went off.
271	1/30	Adenosine triphosphate, disodium salt (same as No. 238).	P	T	-	No reaction.
272	1/30	Same as No. 269, but equivalent to 100 g. flesh, pH adjusted to 7 with NH_4OH.	P	T	X	Speeding and attraction, but no feeding.
273	1/31	Bigeye flesh, extracted with 95% alc., $Pb(Ac)_2$ added to filtrate; filtered; clear filtrate treated with NaCl and heated in water bath for 30 min., tested (equiv. to 400 g. flesh, partially extracted).	P	vW	XXX	Strong attraction but no feeding; visibility poor.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
274	1/31	Same as No. 273, except filtrate, after NaCl treatment put through strong cation exchanger (IR-120) unadsorbed material, equiv. to 400 g. flesh, partially extracted (pH dropped from 7 to 3 as a result of cation treatment).	P	vW	-	No reaction; visibility poor, many ripples
275	1/31	Same as No. 274, except unadsorbed material from cation put through a strongly basic anion exchanger (IRA-400) adsorbed material, equiv. to 400 g. flesh eluted with 1:50 NH_4OH and tested.	P	vW	-	No reaction, visibility poor.
276	1/31	Same as No. 274, except unadsorbed material from cation put through a weakly basic anion exchanger (A-3) and eluted with 1:50 NH_4OH adsorbed material equiv. to 400 g. flesh.	P	vW	-	No reaction, visibility poor.
277	2/5	Same as No. 272, except pH adjusted to 2 with dil. HCl; equiv. to 100 g. flesh.	P	T	-	No reaction.
278	2/5	Same as No. 274, except filtrate put through Duolite C-2 cation exchanger; unadsorbed material equiv. to 400 g. flesh (pH dropped from 7 to 3 as a result of cation treatment).	P	T	X	A weak reaction in first period
279	2/5	Skipjack viscera prep. (HTP), same as No. 264, 200 ml.	P	T	XXX	Good reaction with feedin

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
280	2/5	Bigeye flesh extracted (2nd time) with 95% alc., filtered; filtrate treated with $Pb(Ac)_2$; filtered; filtrate acidified with dil. HCl; filtered; filtrate, equiv. to 250 g. flesh, tested.	P	T	X	A good reaction (possibility of hangover from No. 274 in pipe).
281	2/5	Same as No. 280 except final filtrate evap. to dryness over water bath and dissolved in abs. alc.: alcohol soluble portion, equiv. to 250 g. flesh.	P	T	XX	A good reaction.
282	2/5	Same as No. 280 except final filtrate adjusted to pH-9 with dil. NH_4OH, then put through Duolite A-3 anion exchanger: adsorbed portion eluted with 1:50 NH_4OH, equiv. to 500 g. flesh.	P	T	X	A positive reaction with slight feeding.
283	2/5	Same as No. 282; unadsorbed portion from anion exchanger, equiv. to 500 g. flesh.	P	T	XX	Good reaction with feeding.
284	2/10	Skipjack viscera prep. (HTP) (same as No. 219), 100 ml. "freeze-dried" (brown powder with fishy smell); dissolved in sea water.	P	T	-	No reaction.
285	2/10	Bigeye flesh extracted (3rd time) with 95% alc. filtered; filtrate treated with $Pb(Ac)_2$; filtered; filtrate treated with HCl; filtered; filtrate adjusted to pH-7; passed through IR-120 cation exchanger: unadsorbed portion (pH-2), equiv. to 250 g. flesh, tested.	P	T	-	No reaction.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
286	2/10	Same as No. 285, except unadsorbed portion from cation adjusted to pH 8 with NH_4OH, equiv. to 250 g. flesh, tested.	P	T	X	A good reaction with feeding.
287	2/10	Same as No. 285: adsorbed portions from cation exchanger of No. 280 and No. 281, eluted with 1:50 acetic acid, equiv. to 500 g. flesh, tested.	P	T	XX	Stronger reaction but not much feeding.
288	2/17	Skipjack viscera prep. (same as No. 219), 200 ml., suspended in 200 ml. 95% alc., adjusted to pH 10 with NH_4OH; filtered: filtrate.	P	T	(X)	Some surfacing and perhaps sensing, but no positive reaction.
289	2/17	Skipjack viscera prep. (same as No. 219), 200 ml., suspended in 200 ml. 95% alc., adjusted to pH 2 with conc. HCl; filtered: filtrate.	P	T	(X)	Surfacing but no other good indications of positive reaction.
290	2/17	Skipjack viscera prep. (same as No. 219), 350 ml.: untreated.	P	T	XX	Violent reaction in first 2 periods, with feeding.
291	2/21	Yellowfin flesh extracted with water (HTP) Drum No. 1 (100 lb. to 50 gl.) 5 hours, preserved with 2% $NaHSO_3$, 100 ml.	P	T	XX	Good reaction with feeding; didn't come into field at first.
292	2/28	Bigeye flesh, 500 g. extracted with 95% alc. (1st time); filtered; filtrate adjusted to pH 2 with dil. HCl tested.	P	vW	XX	Visibility poor; feeding reaction; attraction apparent.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
293	2/28	Same as No. 292 except pH-7.	P	vW	XX(X)	Somewhat stronger reaction than No. 292.
294	2/28	Same as No. 292 except adjusted to pH-10 with dil. NH_4OH.	P	vW	XX(X)	About same reaction as No. 293.
295	2/28	Skipjack viscera prep. (same as No. 219), 200 ml. treated with 200 ml. 95% alc., adjusted to pH-2 with HCl; filtered: filtrate.	P	vW	(X)	Sensing but attraction doubtful.
296	2/28	Same as No. 295, except pH-7.	P	vW	X	Definite but weak attraction.
297	2/28	Same as No. 295, except adjusted to pH-10 with dil. NH_4OH.	P	vW	X(X)	Definite but weak attraction; stronger than No. 296.
298	3/7	Bigeye flesh, extracted with 95% alc. (2nd time); filtered; filtrate adjusted to pH-3 with dil. HCl; filtered; filtrate divided into 6 equal parts (each equiv. to 250 g. flesh); Part 1, adjusted to pH-7 with dil. NaOH.	P	vW	(X)	Sensed during 1st. period, but no feeding; remained deep.
299	3/7	Same as No. 298; Part 2, adjusted to pH-10 with dil. NaOH.	P	vW	XX	Fairly strong reaction; definite attraction and feeding.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
300	3/7	Same as No. 298; Part 3, adjusted to pH 10 with dil. NH_4OH.	P	vW	(X)	Excited during 1st period only.
301	3/7	Same as No. 298; Part 4, 0.2 g. $MgCl_2$ added; made basic with dil. NH_4OH; stood overnight; filtered to remove ppte.: filtrate.	P	vW	-	No reaction.
302	3/7	Same as No. 298; Part 5, adjusted to pH 1, boiled 15 min. (to release labile PO_4); neutralized with NaOH, filtered: filtrate.	P	vW	(X)	Sensing but no great excitement; definite reaction in 1st period.
303	3/7	Same as No. 298; Part 6, adjusted to pH 1, boiled 15 min., 0.2 g. $MgCl_2$ added; adjusted to pH 9 with NH_4OH, stood overnight; filtered to remove ppte.: filtrate.	P	vW	XX	Definite attraction with feeding; fish remain deep for most part.
304	3/19	Yellowfin flesh extract (HTP-Drum No. 2; 2/24/53?); 100 lb. to 50 gal. water, extracted for 5 hours, preserved with 2% $NaHSO_3$: 200 ml.	P	T	X	Good reaction for 1st period only: no feeding.
305	3/19	Yellowfin flesh extract (HTP-Drum No. 3; 3/4/53); 100 lb. to 50 gal. water, extracted for 5 hours, preserved with 2% $NaHSO_3$: 200 ml.	P	T	(X)	Slight attraction at beginning?
306	3/19	Skipjack viscera extract (HTP-Drum No. 4; 3/13/53) 100 lb. to 5 gal. water, extracted for 5 hours, preserved with 2% $NaHSO_3$: 200 ml.	P	T	(X)	Very slight, if any attraction.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
307	3/19	Yellowfin flesh extract; same as No. 291 (HTP-Drum No. 1; 2/18/53) 100 lb. to 5 gal. water, extracted for 5 hours, preserved with 2% $NaHSO_3$: 200 ml.	P	T	X	Good reaction during 1st period only; pump off in 4th and 5th period.
308	3/19	Repeat of No. 304 (Drum No. 2); 200 ml. (thrown into pond).	P[4/]	T	XXX	Very good reaction, persisting for 1/2 hour. Surfacing, milling, speeding, feeding.
309	3/19	Repeat of No. 305 (Drum No. 3); 200 ml. (thrown in).	P[4/]	T	(X)	Didn't enter field until 3rd period, weak, if any, reaction.
310	3/19	Second repeat of No. 305 (Drum No. 3); 200 ml. (thrown in).	P[4/]	T	X	Weak reaction.
311	3/19	Repeat of No. 306 (Drum No. 4); 200 ml. (thrown in).	P[4/]	T	X	Weak reaction.
312	3/19	Repeat of No. 307, same as No. 291 (Drum No. 1); 200 ml. (thrown in).	P[4/]	T	XX	Good reaction, once material sensed, with feeding.
313	4/7	Skipjack flesh, 378 g. extracted with 300 ml. water and 83 ml. alcohol; filtered; filtrate treated with $Pb(Ac)_2$; filtered; activity of filtrate adjusted to pH-2; a.m.	P[4/]	T	XXXX	Violent reaction with feeding activity and fighting with Caranx.

[4/] Material thrown in from tower; noise of pump distracts fish.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
314	4/7	Same as No. 313, pH 7; a.m.	P[4]	T	XX	Material drifted rapidly to gates; sensed by *Abudefduf* as well as tunny.
315	4/7	Same as No. 313, pH 10; a.m.	P[4]	T	XX	Delayed reaction with feeding activity. *Caranx* also reacted.
316	4/7	Same as No. 313, pH 2; p.m.	P[4]	T	XX	*Caranx* also reacted; tunny dashing up and down pond.
317	4/7	Same as No. 313, pH 7; p.m.	P[4]	T	XX	Feeding activity.
318	4/7	Same as No. 313, pH 10; p.m.	P[4]	T	X	Weak reaction, but with some feeding activity.
319	4/11	Same as No. 313, pH 2, a.m.	P	vW	XX(X)	
320	4/11	Same as No. 313, pH 7; a.m.	P	vW	X	
321	4/11	Same as No. 313, pH 10; a.m.	P	vW	(X)	
322	4/11	Same as No. 313, pH 2; p.m.	P	vW	X(X)	
323	4/11	Same as No. 313, pH 7; p.m.	P	vW	-	Material lost through faulty hose connection at funnel.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
324	4/11	Same as No. 313, pH 10; p.m.	P	vW	(X)	Three-fourths of material lost as in No. 323.
325	4/14	Same as No. 313, pH 10; a.m.	P	T	X(X)	Little surfacing, no feeding; visibility poor, Caranx reacting.
326	4/14	Same as No. 313, pH-2; a.m.	P	T	X	Remained deep. Visibility poor.
327	4/14	Same as No. 313, pH-2; a.m.	P	T	X	"
328	4/14	Condensed herring solubles (B.C.P.)[5]; 200 ml.	P	T	O	No reaction, but fish didn't enter area after first period.
329	4/14	Same as No. 328	P	T	O	No reaction.
330	4/14	Same as No. 313, pH 10; p.m.	P	T	X	Didn't enter area until 4th period.
331	4/14	Same as No. 313, pH-2; p.m.	P	T	(X)	Sensed material but only turned back once and circled.
332	4/14	Same as No. 313; pH-7; p.m.	P	T	(X)	Slight reaction with feeding; visibility poor; raining.

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[5] British Columbia Packers, Ltd.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
333	4/18	Same as No. 313, pH 10; a.m.	P	vW	(X)	
334	4/18	Same as No. 313, pH 2; a.m.	P	vW	X	
335	4/18	Same as No. 313, pH 7; a.m.	P	vW	XX(X)	Reaction strong in first period.
336	4/18	Same as No. 313, pH 10; p.m.	P	vW	-	Fish didn't enter area during test periods.
337	4/18	Same as No. 313, pH 2; p.m.	P	vW	X	
338	4/18	Same as No. 313, pH 7; p.m.	P	vW	X(X)	
339	4/21	Same as No. 313, pH 7; a.m.	P	T	XX	Slight feeding activity, Caranx also reacting.
340	4/21	Same as No. 313, pH 7; plus furfuryl mercaptan; p.m.	P	T	XX	Tunny didn't enter area until 4th period; Caranx reacting strongly.
341	4/21	Same as No. 313, pH 10; p.m.	P	T	(X)	Didn't enter area until 3rd period; speeding only.
342	4/21	Same as No. 313, pH 2; p.m.	P	T	XXX	Strong reaction with feeding activity.
343	4/25	Same as No. 313, pH 7; a.m.	P	vW	XXX(X)	

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Observer	Reaction	Remarks
344	4/25	Same as No. 313, pH-10; a.m.	P	vW	X(X)	
345	4/25	Same as No. 313, pH-2; a.m.	P	vW	(X)	
346	4/25	Same as No. 313, pH-7; p.m.	P	vW	XXXX	
347	4/25	Same as No. 313, pH-10; p.m.	P	vW	XX(X)	
348	4/25	Same as No. 313, pH-2; p.m.	P	vW	XX(X)	
349	4/28	"Fish lure" (B.C.P), 200 ml.	P	T	X	Reaction during 1st period only.
350	5/19	Skipjack viscera extract (HTP-Drum No. 5; 5/11/53), 300 ml. a.m.	P	T	X	Didn't enter until 3rd period, Caranx reacting.
351	5/19	Same as No. 350; a.m.	P	T	(X)	Caranx reacting better than tunny.
352	5/19	Frozen ground skipjack viscera (HTP-5/11/53), 1 lb. extracted for 1 hour in water, a.m.	P	T	X	Visibility poor.
353	5/19	Same as No. 352, p.m.	P[6]	T	XX	Good feeding activity.
354	5/19	Same as No. 305 (HTP-Drum No. 3 3/4/53) (drawn after sea test of 5/13/53), 500 ml.; p.m.	P[6]	T	X	Slight feeding activity.

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[6] Material thrown from tower, power off.

Expt. No.	Date 1953	Substance and preparation	Tank or Pond	Ob-server	Reaction	Remarks
355	5/19	Same as No. 306 (HTP-Drum No. 4; 3/13/53) (drawn after sea test of 5/13/53); 500 ml.; p.m.	P[6/]	T	(X)	No excitement, sensing only.
356	5/19	Same as No. 352.	P[6/]	T	XX	Good reaction from both tunny and *Caranx*.

Some Opisthobranchiate Mollusca from Hawaii[1]

JENS MATHIAS OSTERGAARD[2]

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INTRODUCTION

IN THE ATTEMPT to advance our knowledge of the marine Mollusca of the Hawaiian Islands, groups provided with a shell have been among the first to receive attention. Largely for this reason gastropods of the order Prosobranchiata, having conspicuous shells, have become better known than have such forms as belong in the order Opisthobranchiata, in which a shell is often absent in the adult.

Such nonshelled forms present difficulty of adequate diagnosis for the establishment of taxonomic characters, inasmuch as the preserved animal soon loses its colors, partly or completely, and becomes in some way distorted because of the contraction of various anatomical parts.

Since the works of Gould (1852) and Harper Pease (1860–1872), nothing appears to have been added to our knowledge of these animals in the Hawaiian area.

The present work is but a small part of what needs to be done in this large group of mollusks, which is well represented in Hawaii. Only those forms whose generic position has already been established are dealt with here. No dissection has been attempted, and specific characters have been based on external features only. The colored figures, as well as those in black and white, have been reproduced from the author's water-color drawings.

The holotypes of all new species are deposited in the United States National Museum, paratypes and other specimens cited are in the Bernice P. Bishop Museum, Honolulu.

Acknowledgments: For his fine aid rendered over a long period of time in securing specimens for me, I am very grateful to Dr. Charles H. Edmondson. I am thankful to Otto Degener for many interesting specimens. During the last 2 years, while preparing this manuscript for publication, I received from Mr. Charles Cutress of the University of Hawaii many specimens of opisthobranchiates, for which I am very appreciative. Mr. Spencer Tinker, director of the Honolulu Aquarium, has rendered me valuable services by retaining for me many fine specimens of nudibranchs. For the aid in taxonomic problems so generously given me by Dr. Frank M. MacFarland, I feel a sincere appreciation. Finally, I must express my deep gratitude for the aid rendered and interest shown in this undertaking by Dr. Robert W. Hiatt, director of the Hawaii Marine Laboratory.

KEY TO INCLUDED GENERA OF HAWAIIAN OPISTHOBRANCHIATA

1. Respiratory organs, when present, concealed under mantle or attached to right side of body or consisting of respiratory

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folds; shell present or absent in the adult (suborders Tectibranchiata and Ascoglossa) 2

Respiratory organs consisting of a circle of gills surrounding the anal papilla, or of branchial processes covering the body; shell and mantle absent in the adult (suborder Nudibranchiata) 10

2(1). Shell more or less conspicuous and generally covering mantle and gills . . . 3

Shell absent in adult; respiratory folds, when present, not in the form of gills . . 9

3(2). Gills on dorsal side of body, usually covered by shell or mantle 4

Gill consisting of a plume on right side of body . . . . **Pleurobranchus**

4(3). Shell large and almost capable of concealing the animal 5

Shell rudimentary and nearly or entirely concealed from view 7

5(4). Parapodial lobes extending the whole length of animal . . . . **Hydatina**

Parapodial lobes covering anterior part of shell 6

6(5). Shield extending from foot to cover posterior part of shell . . . . . . **Haminoea**

No shield covering posterior part of foot . . . . **Atys**

7(4). Shell and mantle covering gills between parapodial lobes 8

Shell and mantle rudimentary or absent . . . . **Notarchus**

8(7). Shell hatchet-shaped; body of animal tapering anteriorly and obliquely truncate posteriorly . . . . **Dolabella**

Shell somewhat oval in outline; body of animal slender and fusiform . . . . . **Tethys**

9(2). Parapodial lobes united dorsally by regular margins; their inner surfaces covered with longitudinal narrow branchial folds supporting commensal algae . . . . **Placobranchus**

Parapodial lobes with folded margins not fully united dorsally; no branchial folds present . . . . **Elysia**

10(1). Respiratory organs consisting of a circle of gills surrounding anal papilla . 11

Respiratory organs consisting of branchial processes covering the body . . . 13

11(10). Cloak of great lateral spread and produced into swimming lobes folded on the sides when the animal is at rest . . . . **Hexabranchus**

Cloak narrow and not used as swimming lobes, nor folded when the animal is at rest 12

12(11). Body slender, bluish white with interrupted blue striae. Gills simple pinnae, white, with bands of orange . . . . **Glossodoris**

Body elongate, about one third as wide as long, bluish black with fine white specks. Gills with long lateral branches . . . . **Doridopsis**

13(10). Body broad anteriorly, tapering posteriorly and covered with numerous slender branchial papillae. Rhinophores and oral tentacles simple . . . . . **Aeolidia**

Body slender, fusiform, beset with two rows of broad branchial processes. Rhinophores placed on dorsal side of an extensive oral veil . . . . **Melibe**

CLASSIFICATION OF SPECIES CONSIDERED

Suborder Tectibranchiata
  Family Scaphandridae
    Genus *Atys*
      (*A. semistriata*)
  Family Akeridae
    Genus *Haminoea*
      (*H. crocata*)

Family Hydatinidae
  Genus *Hydatina*
    (*H. physis*)
  Family Aplysiidae
  Genus *Tethys*
    (*T. elongata*)
  Genus *Notarchus*
    (*N. lineolatus*)
  Genus *Dolabella*
    (*D. variegata*)
  Family Pleurobranchidae
  Genus *Pleurobranchus*
    (*P. delicatus*)

Suborder Ascoglossa
  Family Placobranchidae
    Genus *Placobranchus*
      (*P. ianthobapsus*)
  Family Elysiidae
    Genus *Elysia*
      (*E. elsieae*, *E. degeneri*, *E. nealae*)

Suborder Nudibranchiata
  Tribe Holohepatica
    Family Dorididae
      Genus *Glossodoris*
        (*G. prismatica lineata*)
      Genus *Doridopsis*
        (*D. macfarlandi*)
    Family Hexabranchidae
      Genus *Hexabranchus*
        (*H. tinkeri*, *H. aureomarginatus*)
  Tribe Cladohepatica
    Family Aeolidiidae
      Genus *Aeolidia*
        (*A. edmondsoni*)
    Family Fimbriidae
      Genus *Melibe*
        (*M. pilosa*)

Atys semistriata Pease
Fig. 1

Atys semistriata Pease, Zool. Soc. London, Proc. 1860: 20.

Atys semistriata Pease. Tryon and Pilsbry, Man. Conch. 15: 267, pl. 28, fig. 30, 1893.

A living specimen of *Atys semistriata* was obtained off the Hawaii Marine Laboratory at Waikiki in August, 1921. During its captivity this specimen deposited an egg mass, which has been described and figured, including the veliger larval stage (Ostergaard, 1950: 105).

When the animal is active and fully extended, it is 13 millimeters in length. Head shield broad, truncate anteriorly, bilobed posteriorly, lobes small and rounded. Epipodial lobes extending over anterior half or body, meeting middorsally to cover anteriof part of shell. Foot bilobed; anterior portion truncate and larger than posterior portion, which tapers to a broadly rounded extremity. Color pale bluish white and peppered with minute black specks. Mantle, visible within the semitransparent shell, also pale bluish white with crowded masses of well-defined longitudinally elongate carmine spots. Eyes conspicuous, located between lobes of head shield.

The description of the shell by Pease is as follows:

"Shell oval contracted posteriorly, thin, fragile, pellucid, white, transverse raised lines at both ends; aperture slightly dilated at the base; apex perforate."

Haminoea crocata Pease
Fig. 2

Haminoea crocata Pease, Zool. Soc. London, Proc. 1860: 19.

Haminoea crocata Pease. Tryon and Pilsbry, Man. Conch. 15: 363, 364, pl. 40, fig. 3, 1893.

From a group of seven specimens of living animals collected during March, 1923, at Waianae, Oahu, a description of the external parts of this vividly colored animal is as follows:

Animal somewhat fusiform, truncate anteriorly and bluntly pointed posteriorly. Cephalic disc large, truncated anteriorly, bilobed posteriorly, lobes long with rounded extremities. Eyes minute, located anterolaterad of anterior division of cephalic lobes. Epipodial lobes large, reflexed over, and partly covering, the shell. A posterior shield extending dorsally to cover posterior part of shell. Foot divided into a larger anterior and a smaller posterior portion. Anterior portion truncate at both ends; posterior portion truncate anteriorly and bluntly rounded posteriorly. Both portions of foot continuous with epipodial lobes and posterior shield, respectively. All external parts of animal pale blue with faint purple blotches and with numerous bright orange spots of various sizes scattered quite evenly over all. Mantle visible through semitransparent shell, dark green with large orange hieroglyphs and small round dark-red spots.

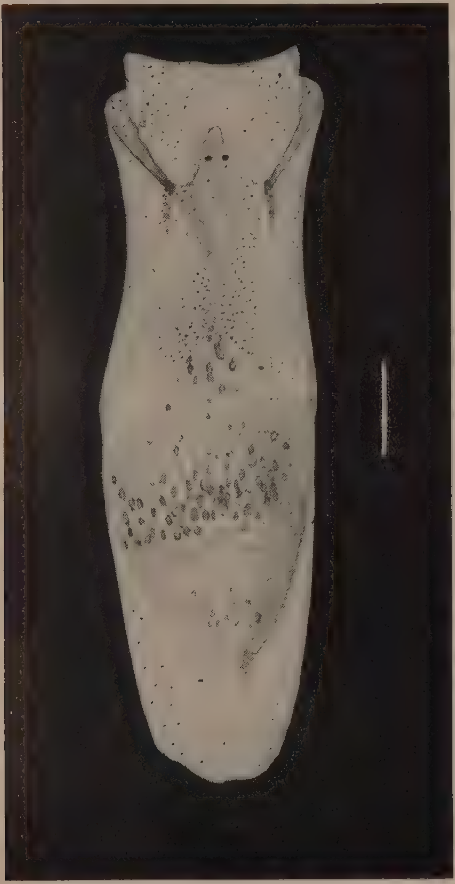


FIG. 1. *Atys semistriata* Pease, dorsal aspect (× 8).

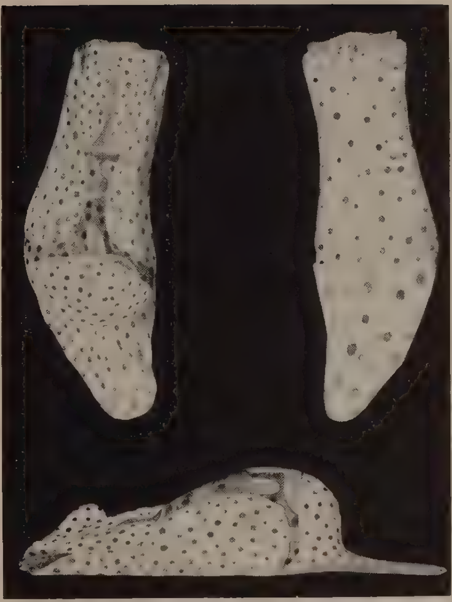


FIG. 2. *Haminoea crocata* Pease, dorsal, ventral, and lateral aspects (× 2).

Length of animal, when creeping and fully extended, is 3 centimeters.

Tryon and Pilsbry (1893: 363–364) give the following description of the shell:

> Shell ovate-elongate, moderately solid, yellow, becoming orange on the latter part of the last whorl, and opaque above and below. Surface shining, showing slight, irregular growth-wrinkles and excessively fine, close, superficial spiral crenulated striae. Vertex narrow, very slightly impressed, imperforate or nearly so, opaque white in the center; lip inserted on the right of the center of the vertex, thickened; outer lip well curved; columella moderately concave, with a reflexed white callus, not folded above.
>
> Alt. 13, diam. 8½ mm. Sandwich Is.

A description and figures of the egg structure of this mollusk are given in Ostergaard (1950).

Hydatina physis (Linnaeus)

Fig. 3

Bulla physis Linn., Syst. Nat., p. 727, 1758.

Hydatina physis Linn. Tryon and Pilsbry, Man. Conch. 15: 387, 388, pl. 45, figs. 14–17, 1893.

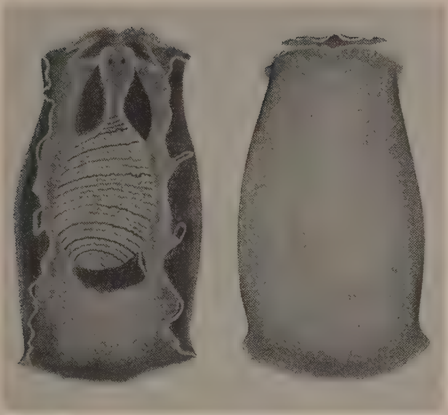


FIG. 3. *Hydatina physis* (Linnaeus), dorsal and ventral aspects (ca. × 1.3).

Animal large and when active about three times as long as its shell. Head disc with four lobes of about equal size bluntly pointed at their tips. Two large, ear-like lobes extending posteriorly from head disc, partly covering anterior part of shell. Foot very broad and continuous with dorsally directed parapodial lobes; truncate at both ends, widest posteriorly. Parapodial lobes much folded along margins, which are partly flexed over shell. Foot, both dorsally and ventrally, bluish purple, merging into a vivid brown toward margins. Head disc, anterior lobes, and mantle vivid brown, edged like anterior and posterior margins of foot with bluish or greenish white. Eyes conspicuously placed posterior to head disc. Gill pale bluish purple, turned inward at tip, and about 5 mm. in length, with 18 or 20 plumules. Length of animal about 4 cm.; length of shell 16 mm.

The specimen here described and figured was obtained during the latter part of June, 1922, at Kawailoa, Oahu, where it was found among a number of *Hydatina amplustre*. Other specimens have been found off the Hawaii Marine Laboratory at Waikiki.

The characters of the shell correspond well with those of the typical form figured and described by Tryon and Pilsbry (1893: 387, pl. 45). The description is as follows:

> Shell large, globose or oval, thin; under a thin buff cuticle the shell is white, with many close wavy brown spiral lines. Surface very slightly and coarsely waved longitudinally, otherwise smooth. Vertex flat, the spire about level; whorls about 3½, the first a minute globose, uptilted and half immersed nucleus, the rest separated by deep sutures. Body-whorl globose above, somewhat attenuated below, where there is a convex spiral rib surrounding the umbilical tract; aperture about as long as the shell, large, ovate, narrower and curved above, dilated below. Lip simple and thin, very little retracted toward its upper insertion, rounded at base, bluntly angled at foot of the columella. Columella gently concave or nearly straight, with reflexed edge, leaving an umbilical chink or rarely none.

Spawn and the veliger stage of the larva are described and figured in Ostergaard (1950).

Tethys elongata (Pease)
Fig. 4

Siphonata elongata Pease, Zool. Soc. London, Proc. 1860: 24.

Tethys elongata Pease. Tryon and Pilsbry, Man. Conch. 16: 93, pl. 59, figs. 35–38, 1895–96.

Because of the rather strikingly different coloration of some of my specimens of this animal, they might appear to be different from the specimens of *T. elongata* (Pease), which is common on seaweeds along the leeward shores of Oahu; but after a study of them and a comparison with typical forms, I concluded that they constituted a color variation, merely, as no different characters could be discerned either in their external anatomy or shell.

I enter herewith a description of this color form:

Body elongate fusiform, slender, terminating posteriorly in an obtuse point. Rhinophores erect with acutely pointed extremities, and widely slit throughout the distal half of their length. Anterior, or labial, tentacles involute, broad and flaring in their proximal half. Foot rounded anteriorly and obtusely pointed posteriorly. Parapodial lobes high, ample, and folded, occupying the middle third of the body. To the left of the mantle, from which the wide, flaring siphon extends, can be seen a portion of the shell. Genital

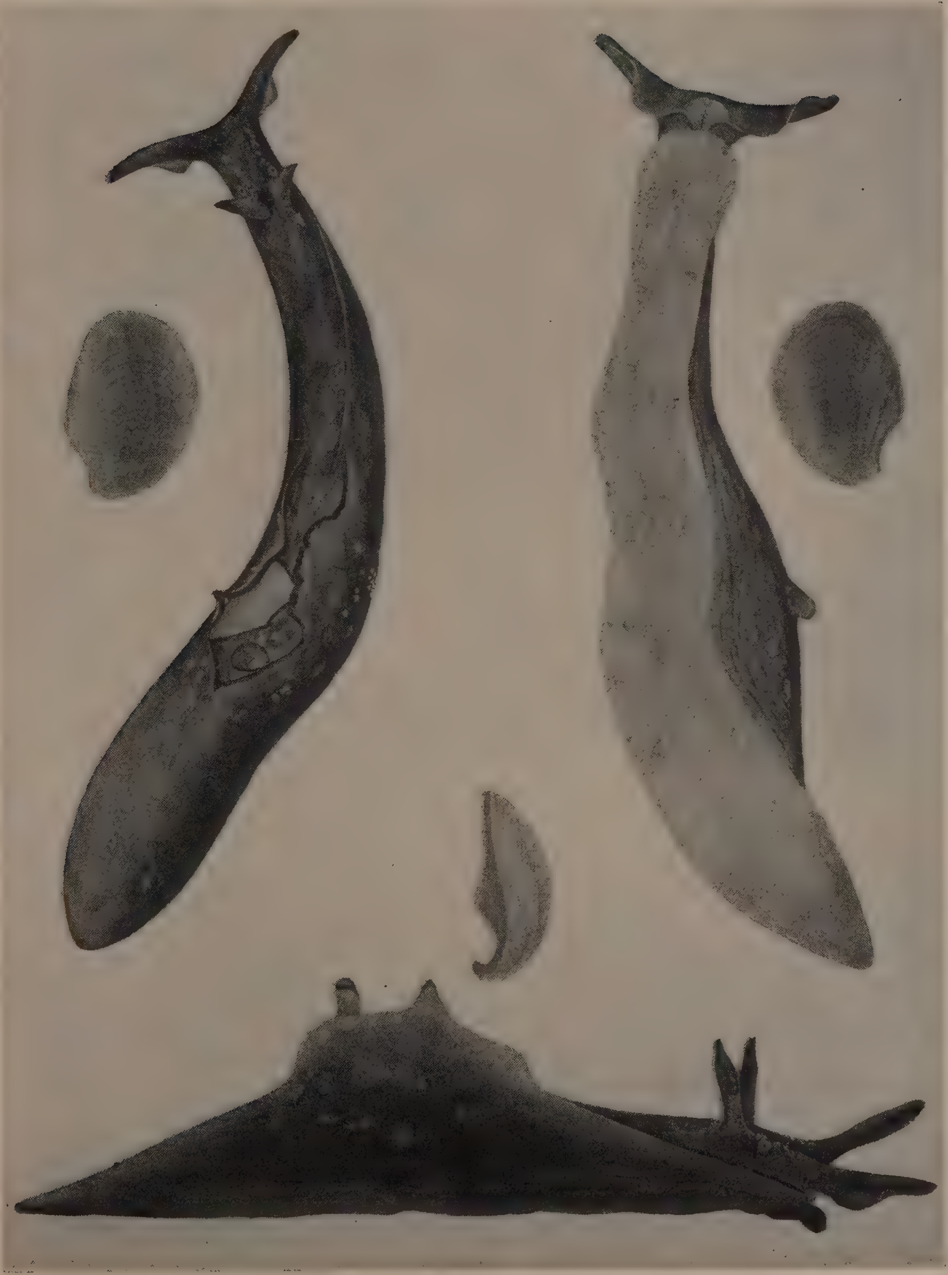


FIG. 4. *Tethys elongata* (Pease), dorsal, ventral, and lateral aspects of animal (× 4.3) and shell.

groove conspicuous, extending from genital pore, between anterior margins of parapodial lobes, anterolaterad to base of right labial tentacle, where penis is located. Eyes, anterolaterad of rhinophores, conspicuous for their broad white rings. Body and head dark purplish brown with sprinkles of groups of fine white specks, particularly in region of parapodial lobes. Sole of foot cream yellow. When disturbed, the animal emits a purplish carmine fluid. Length of body 31 millimeters.

Shell large, yellowish olive green, 8 millimeters in length, deeply concave with prominent beak. Radial lines and growth lines distinct.

Seven specimens of this color form were found near the Hawaii Marine Laboratory, Waikiki, during May, 1923, where some of the typically colored forms also occurred. It will be noted in the specimen described and figured that the parapodial lobes are edged with black, and that rhinophores and labial tentacles are tipped with the same color. In some of the specimens this color was reversed, these areas being white instead of black.

Description and figures of egg filament, cleavage, and veliger stage are given in Ostergaard (1950: 100).

Notarchus lineolatus (Gould)

Fig. 5

Stylocheilus lineolatus Gould, U. S. Expl. Exped., Moll., p. 225, pl. 16, figs. 270, 270a, 1852.
Notarchus lineolatus Gould. Tryon and Pilsbry, Man. Conch. 16: 140, pl. 29, figs. 37–39, 1895–96.

Body from 2.5 to 4 centimeters in length, elongate, fusiform, tapering to acute point posteriorly. Parapodial lobes swollen and rounded, broadly united behind, almost meeting in front. Gills large and arched, convex posteriorly, concave anteriorly, bluish with fine brown veins and white specks; mantle very rudimentary, not covering the gills. Anal papilla long, slender. Anterior tentacles loosely involuted; from them a pair of small obtuse lobes extending posterolaterad of buccal disc. Rhinophores long, cylindrical, tapering slightly toward their extremities, slit in the distal half. Integument of rhinophores and anterior tentacles raised into small white or yellowish conical cirri. Similar, but larger, cirri occur throughout body region; largest at margins of parapodial lobes where some of them are branched. Foot slightly narrower than body, truncate anteriorly and tapering posteriorly to acute point. Foot pale bluish green, darker where viscera show through, marked throughout with numerous interrupted light brown striae, and in some specimens, especially in young individuals, sprinkled with minute white specks. Head, body, and dorsal surface of foot marked with fine, longitudinal, closely crowded, wavy, dark-brown lines, and with irregularly scattered ocelli whose pupils are blue with a dark brown ring and a light brown outer zone.

In quite young animals the ocelli are wanting, the dorsal striae are few and comparatively heavy, and the cirri are all unbranched. In specimens of 5.5 millimeters length, cirri may not be present. In intermediate stages of growth, the observed transition between young and adult seems to indicate that changes of color and structure take place gradually.

When disturbed, the animal emits a clear bluish-purple fluid.

The following is Gould's description of *Notarchus lineolatus:*

> Animal elongated, delicately attenuated posteriorly, of a pale grass-green color, ornamented with longitudinal, parallel, contorted, rusty lines, and scattered ocelli of unequal size. The papillae of the mantle [he evidently mistook the parapodial lobes for the mantle] are branching. The anterior tentacles are short, tapering, and destitute of papillae.
>
> Length three and a half inches.
>
> Found on a coral reef at Honolulu, Oahu.

The animals were found at Kawailoa, Oahu, during June, 1922, where they occurred in large numbers on seaweeds, upon which they appear to feed. A rather pale variety has been found at Waikiki. From Nanakuli, Oahu, 15 specimens were obtained in March, 1921.

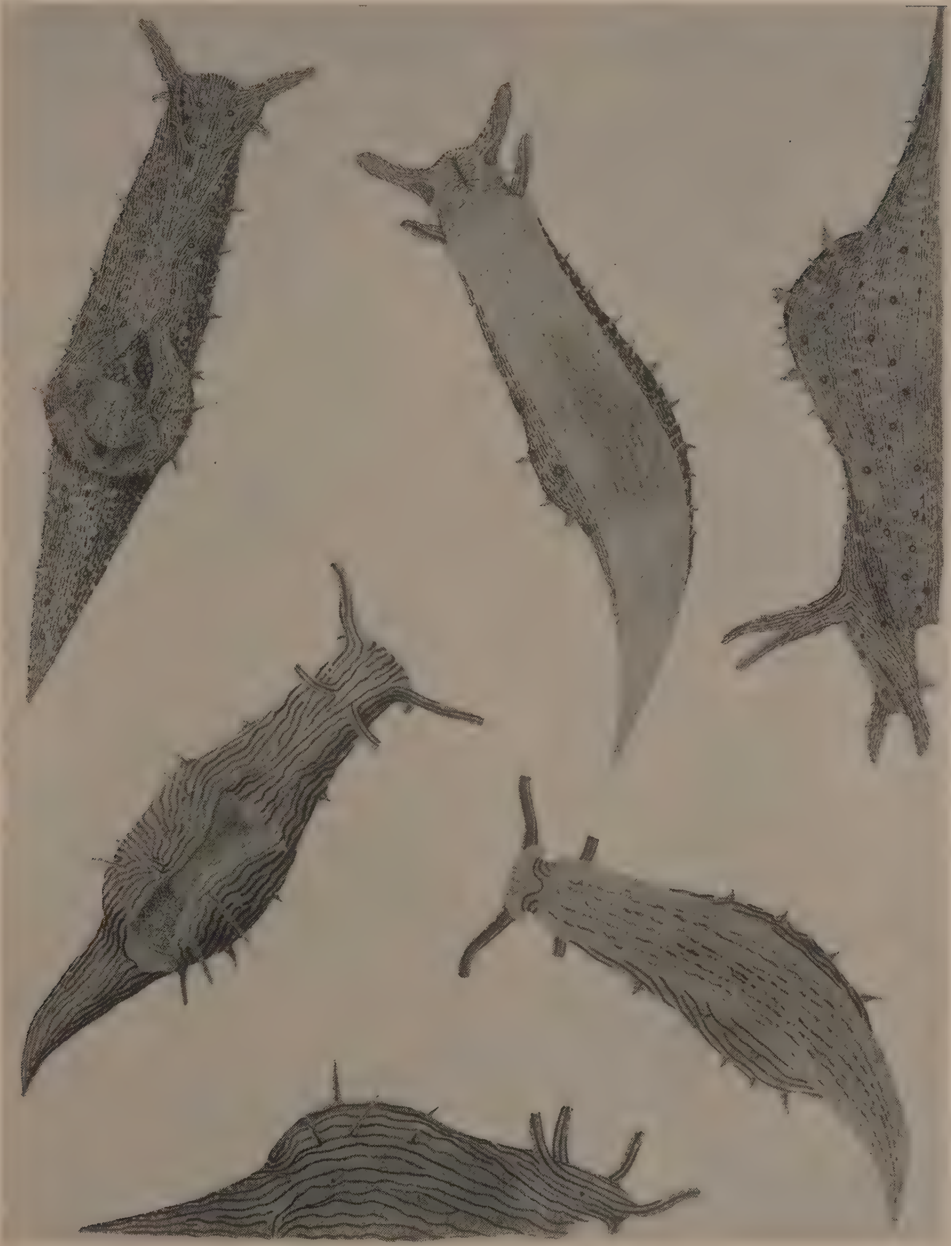


FIG. 5. *Notarchus lineolatus* (Gould), dorsal, ventral, and lateral aspects. Upper, mature; lower, juvenile (ca. × 3).

These ranged in length from 12 to 57 millimeters. The figured example is 32 millimeters in length.

These mollusks are very prolific egg layers during June and July, at which time they festoon their pale-green thread-like filaments on every object with which they come in contact.

A description of the spawn, development, and veliger stage of this species is given in Ostergaard (1950: 101–102). In that publication the species has been erroneously named *Notarchus striatus* Quoy and Gaimard, which it resembles quite closely.

Dolabella variegata Pease

Fig. 6

Dolabella variegata Pease, Zool. Soc. London, Proc. 1860: 22.

Dolabella variegata Pease. Tryon and Pilsbry, Man. Conch., 16: 155, 156, pl. 28, figs. 33–36, 1895–96.

Animal oblong, conical, tapering anteriorly, obliquely truncate posteriorly. Head and body covered with small acute tubercles, which are scabrous and furnished with pale, soft cirri. Parapodial lobes closely appressed, the left tending to overlap the right, leaving two dorsal openings—one a little anterior to point of truncation, other at center of body. Rhinophores stout, involute, and open laterally. Oral tentacles short, stout, dilated distally and open laterally. Eyes located anterolaterad to rhinophores. Foot truncate anteriorly and obtusely rounded posteriorly, widest one-fourth distance from posterior end. Greenish olive, variegated with brown, white, and green. Foot greenish brown, clouded with olive green, evenly sprinkled with fine, round, pale-brown spots.

Dorsal aspect in Figure 6 of a specimen 17 centimeters long with a transverse diameter, at its widest part, of 8 centimeters, other illustrations taken from smaller specimens.

Specimens with a green coloration predominating have been found at Waikiki.

Shell hatchet-shaped, strongly curved with one nuclear convolution from which a fold extends around the apex. Proximal margin broad; growth lines numerous, fine. Color yellowish white and pink toward apex. Length 30 millimeters, width of proximal border 21 millimeters.

Pleurobranchus delicatus (Pease)

Fig. 7

Pleurobranchus delicatus Pease, Zool. Soc. London, Proc. 1861: 245.

Pleurobranchus delicatus Pease. Tryon and Pilsbry, Man. Conch., 16: 202, pl. 45, figs. 7–9, 1895–96.

Animal delicate, subpellucid, cloak smooth, oblong oval, rounded at both extremities, transversely convex. Foot, elongate oval, may or may not extend beyond cloak. Rhinophores rather short, involute, with truncate extremities. Oral veil triangular with anterior border straight and of greatest width, narrowing gradually toward head. Eyes placed on dorsolateral side of head and near base of rhinophores. Branchial plume on right side of body, nearly half as long as animal, bipinnate, with about 28 pairs of pinnules; pink. Genital apertures distinctly separate, near anterior end of body on right side. Length of body 44 millimeters, width 22 millimeters.

The shell is small and corresponds well with the description given by Pease, which I quote here:

> Shell small, rather solid, subpyriform, elongate, narrow posteriorly, rounded in front, slightly flexuous; surface rough and marked with prominent lines of growth; nucleus spiral, anterior portion stained with violet, posteriorly white or light horn color.

The color of the cloak is bright orange; that of the foot, rhinophores, and oral veil is pale pink bordered with orange. The dark-colored viscera may be seen through both foot and cloak.

Four specimens were found off the Hawaii Marine Laboratory at Waikiki in October, 1922. An additional four specimens were

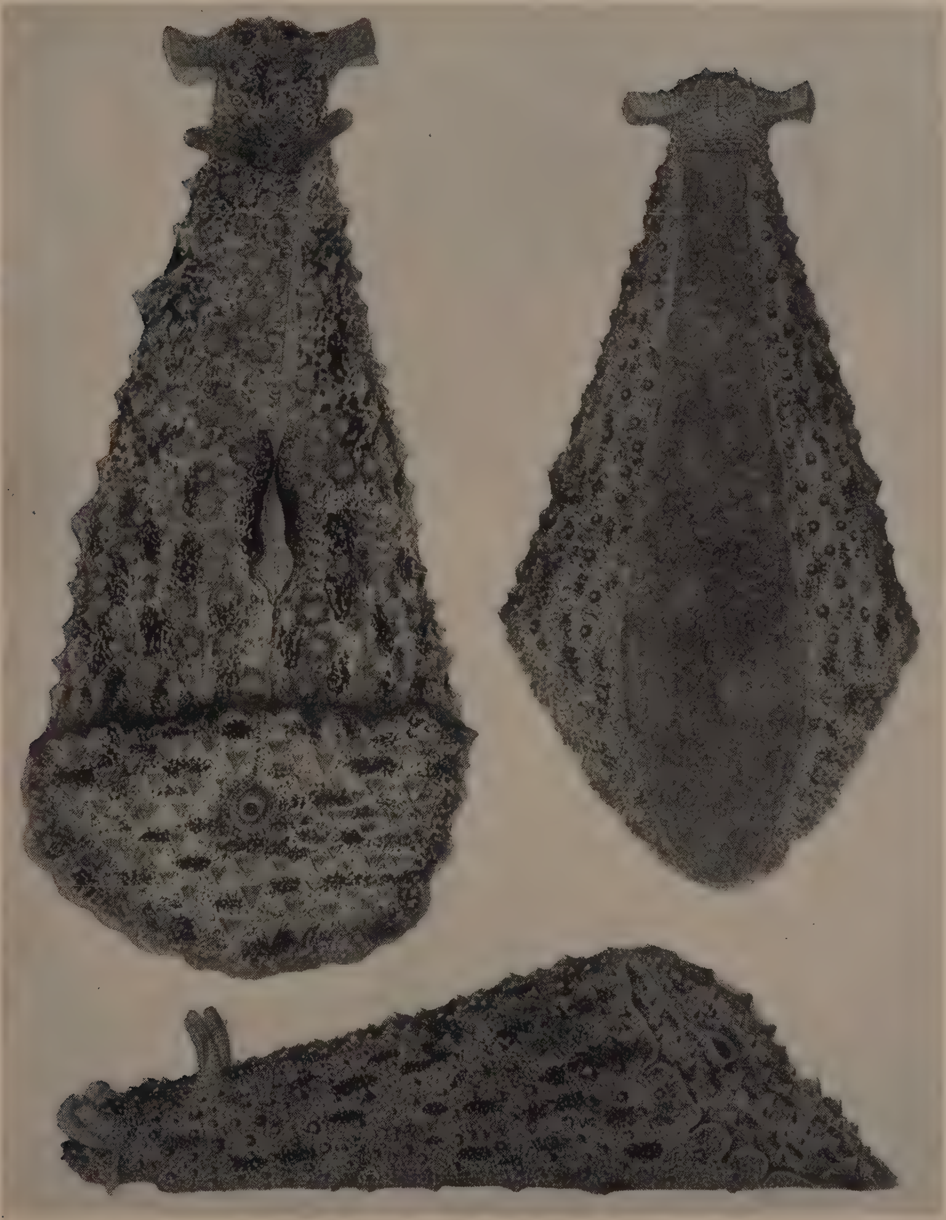


FIG. 6. *Dolabella variegata* (Pease), dorsal, ventral, and lateral aspects (× 0.8).

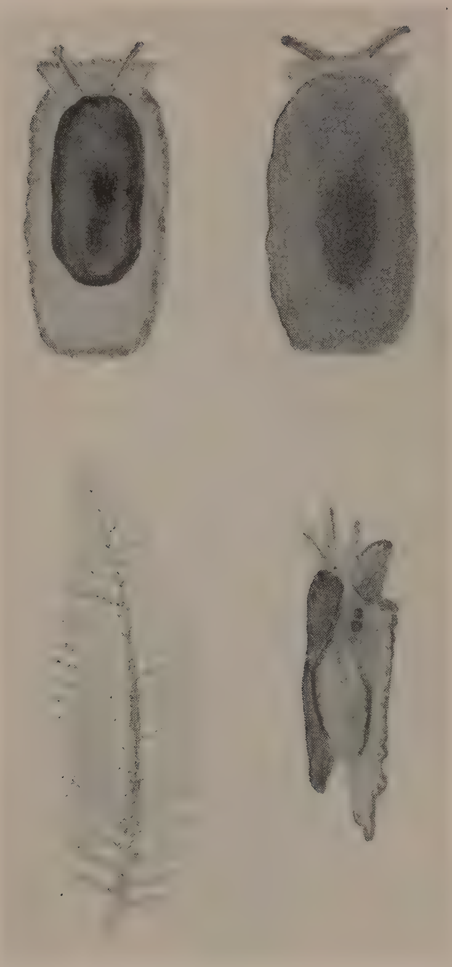


FIG. 7. *Pleurobranchus delicatus* (Pease), dorsal, ventral, and lateral aspects (natural size); branchial plume (enlarged).

found on windward Oahu, near Makapuu, June 30, 1950.

The specimen I have figured (the first one obtained) has a much smaller cloak than others (obtained later) which agree with Pease's description. It is possible that the cloak might have been injured and was in process of regeneration.

Placobranchus ianthobapsus Gould
Fig. 8

Placobranchus ianthobapsus Gould, U. S. Expl. Exped. 12: 307, pl. 26, figs. 407a–c, 1852.

Body elongate, dorsoventrally compressed, tapered slightly toward truncate posterior extremity. Oral hood broad, lateral continuations of which form the tentacles. Mouth situated ventrally, within cavity formed by hood. Tentacles involute, retractile apically, tapering distally, directed laterad at base and distal ends usually turned slightly upward and forward, much like the horns of an ox. They are whitish yellow to vivid greenish yellow, with tips of pale reddish purple that tends to form a band of a deeper tinge. Dorsal surface light yellowish green to pale green, in some specimens clouded with olive green or olive brown. Ocelli crowding surface of head and body, of three types: (1) small, numerous bodies with yellow or brownish-orange pupil surrounded by a white iris; (2) a larger and less numerous type with yellowish or olive-green pupil with light-green center and white iris surrounding pupil; (3) the largest type and least numerous, with greenish or sky-blue pupil surrounded by a thick black ring and usually without the white iris. These ocelli are usually promiscuously scattered and intergrade with one another; but in some individuals they tend to become arranged bilaterally on the dorsal surface, especially the large black-ringed type, which are always numerous along the lateral margin of the foot. Eyes small, retractile, placed in shallow orbits on lateral sides of an anteriorly pointing prominence on the middorsal side of head. Branchial surface pale green with numerous longitudinal folds crowded with grass-green algae. Cardiac swelling triangular, white and prominent, placed directly posterior to the head. Margins of the body, meeting middorsally, thick, pellucid, whitish blue with a series of opaque yellowish-green oval or oblong bodies. Foot bluish green with numerous ocelli of unequal sizes with pupils from olive

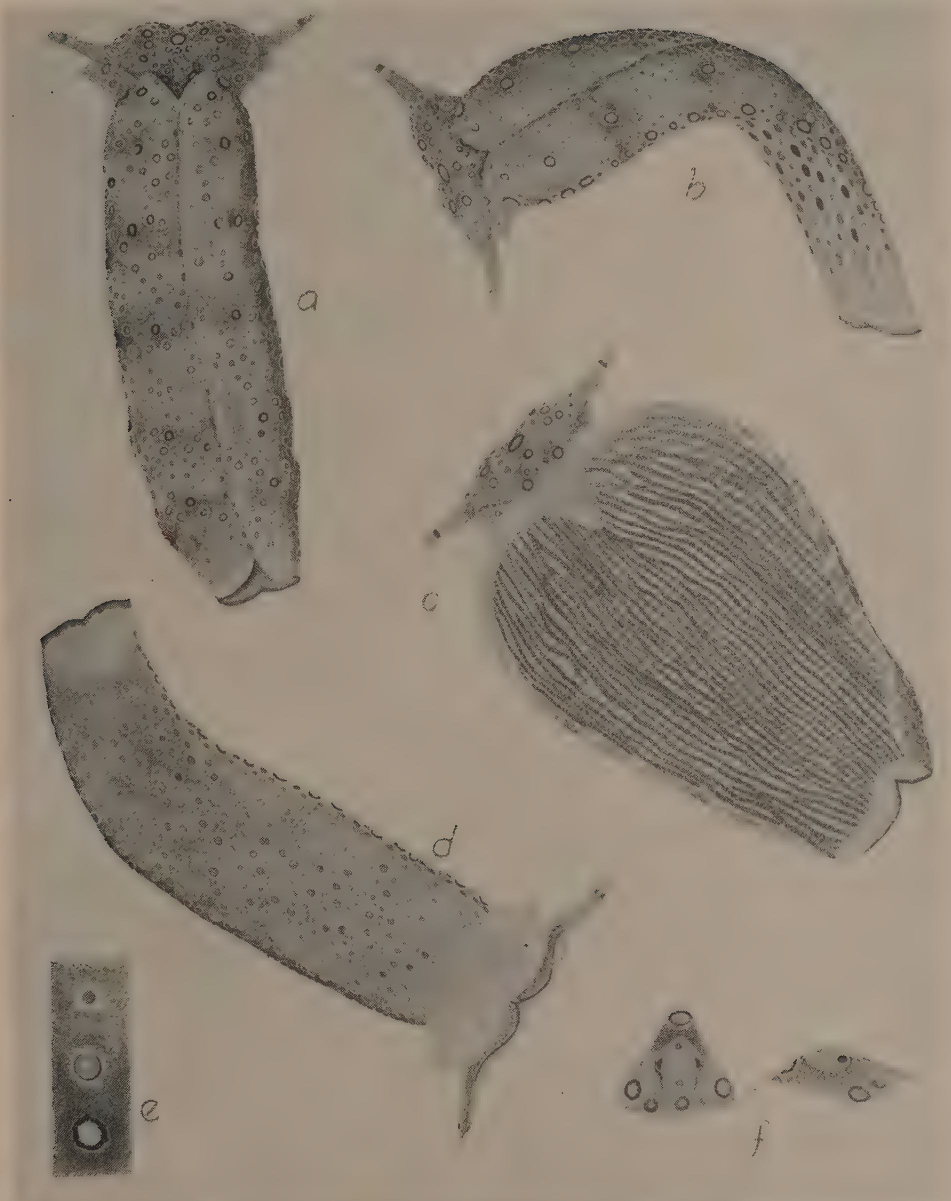


FIG. 8. *Placobranchus ianthobapsus* Gould. *a*, Dorsal aspect; *b*, creeping individual; *c*, expanded to show branchial surface with rows of symbiotic algae; *d*, ventral aspect; *e*, three principal types of ocelli; *f*, details of dorsum of head showing eyes. (*a*, *b*, *c*, *d*, ca. × 8.6; *e*, *f*, greatly enlarged.)

green to dark brown surrounded by a white iris. Posterior end of foot and anterior margin of oral hood bordered with purple. Anteriorly, foot partly divided into a triangular, laterally extending lobe with a few ocelli on posterior portion of its ventral surface; ocelli on dorsal side resembling those of second type. Posterior region of foot unmarked and merging into a very pale bluish green, extending to its purple border. Length of animal 5 centimeters.

The following is Gould's description:

> Body elongated, in the form of a three-sided prism, terminating abruptly, as if torn off behind. Head broad, heart-shaped in front, lip edged with violet; tentacles involute, as if formed by an extension of the angles of the hood; ochreous tipped with white, annulate with violet near the lip [*tip* must have been intended for the word *lip*], retractile at tip. Colour of the back yellowish, shaded with olive, ornamented with two sets of ocelli, the larger in two series of eight on each side, with a blue pupil and white iris, and numerous smaller ones with orange pupil and white iris; foot not distinct from the body except in colour, emerald green, with the blue and orange ocelli smaller, and more nearly equal in size than those of the back. Margins of the body dilated and folded upon the back; branchial folds grass-green, radiating from the cardiac swelling behind the head.
>
> Length two and a half inches; breadth five-eighths of an inch.
>
> Found upon a coral reef at Honolulu, Sandwich Islands.

A study of his figures, alone, would lead me to conclude that Gould's species is different from mine; but, from the reading of his description, which clears up defects in the figures, I am led to believe that they are identical.

HABITAT: On mud flats at Coconut Island, Kaneohe Bay, Oahu, where many specimens have been obtained from time to time. Specimens have been obtained from Kahala, others from the Island of Molokai, the latter being but half the size of those found in Kaneohe Bay.

All specimens obtained agree closely in structure and coloration, and they seem to show no seasonal fluctuation in their occurrence.

The spawn and larval stage is described and figured in Ostergaard (1950: 107–108).

Elysia elsieae sp. nov.

Fig. 9, Pl. 1

Body slender, elongate, tapering posteriorly to an acute point. Parapodial lobes thick and wavy. Rhinophores long and of equal diameters, curved anterolaterad with extremities directed laterally. Eyes very prominent, placed posterior to lateral base of rhinophores. Foot truncate anteriorly and tapering to acute point posteriorly. Head shield continuous laterally with rhinophores. Penis on right side about one-fourth distance from anterior end. Mouth, somewhat indistinct, located on head shield near its ventral margin. Color of body and foot pale bluish green; foot flecked with white. Body and both surfaces of parapodial lobes crowded with white and with black round spots of various sizes. Margins of parapodial lobes edged with pale pinkish carmine bordered with golden yellow and dark-green lines. Rhinophores pink with an irregular band of carmine near base and with purple extremities; within, pink color is heavily peppered with minute black specks. Similar peppering found on head shield. Heart, as prominent swelling, appearing between anterior ends of parapodial lobes.

Length of animal 15 millimeters, width 2.5 millimeters.

Holotype (U.S.N.M. 574928), May 1924, off Hawaii Marine Laboratory, Waikiki.

The figures are made from what appears to be an immature specimen, obtained in June, 1922, off the Hawaii Marine Laboratory, Waikiki, and which was about half the length of the many other specimens gathered later from the same locality, where they were abundant during the summer of 1924 in shallow water close to shore, on algae or on the sand.

I have named this beautiful little species for my daughter Elsie for the interest and enthusiasm she showed in my pursuit of its study.

In some specimens, the larger black spots appear as thick rings with small white pupils. In others, the white spots on the lateral sides

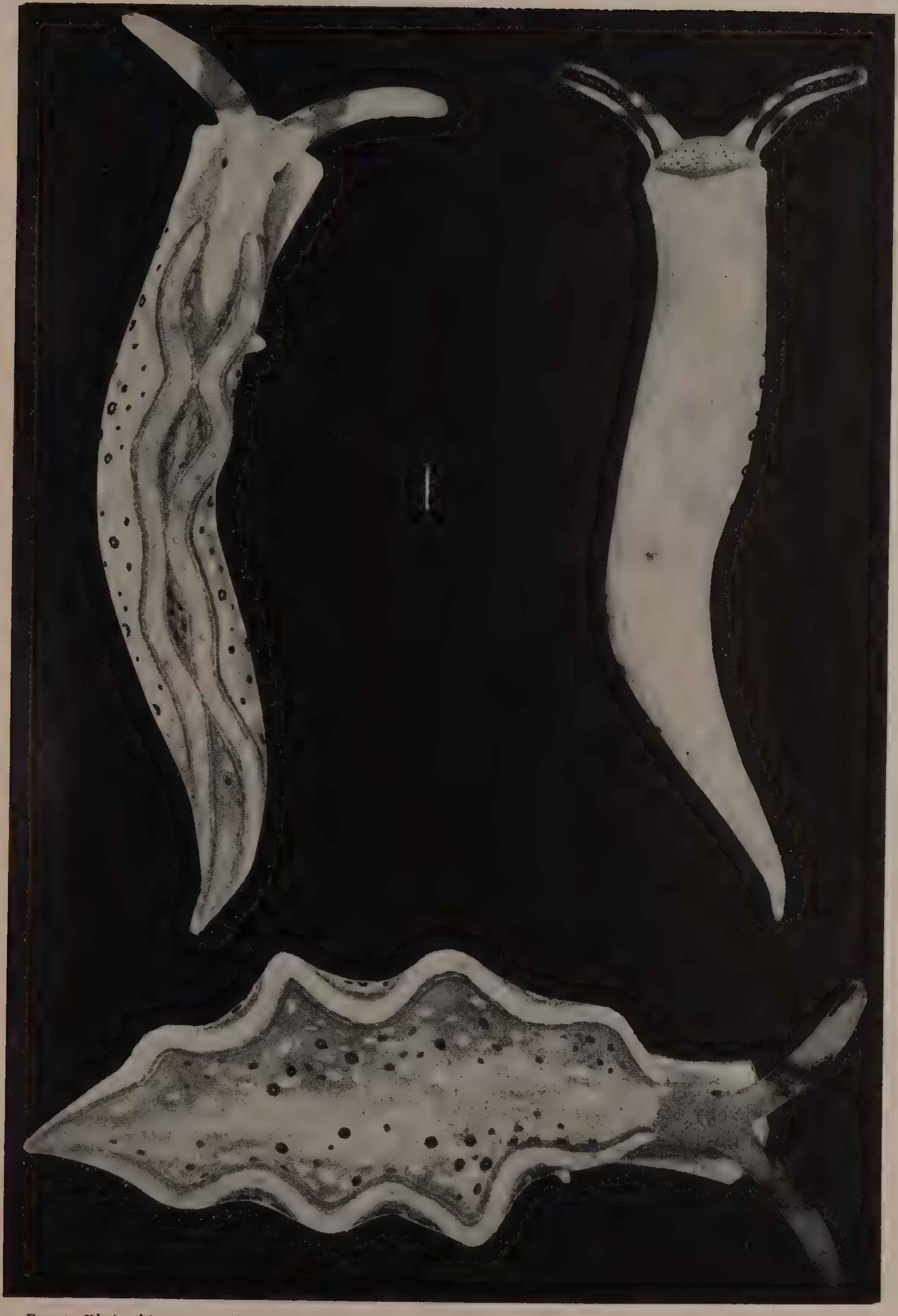


FIG. 9. *Elysia elsieae* n. sp., dorsal and ventral aspects with mantle closed and (lower) dorsal aspect with mantle expanded (× 19).

of the parapodial lobes were elevated into conical papillae. The animals would often float at the surface of the water in an inverted position.

The egg filament and development of the larvae are described and figured as *Elysia* sp. in Ostergaard (1950: 108).

The species admits of comparison with *Elysia lobata* Gould (1852: 308, pl. 26, figs. 405, 405a).

Gould's description is as follows:

> Corpus limaciforme, gracile, dilatatum, trilobatum, viirescens nigro-punctatum; palium utrinque flavo-marginatum: tentaculae elongatae.
>
> Animal slug-like, greenish, dotted with black and bordered with yellow; edge of the mantle expanded into a three-lobed lateral wing. Head small with very large and long tentacles, tipped with sky-blue; eyes situated laterally, a little behind the tentacles. In creeping it flaps downwards, at pretty regular intervals, its long, ear-like tentacles. There are no apparent branchial organs, not even the plaits along the back, as in Placobranchus, to which it is otherwise evidently allied; the parts about the mouth seem to have been imperfectly figured.
>
> Length one inch.
>
> Found creeping on coral stems, like a small *Doris*, at Honolulu. Dr. Pickering.

Both Gould's description and figures of this species are inadequate, and it is therefore not possible to determine whether his species is identical to this.

Elysia degeneri sp. nov.
Fig. 10, Pl. 1

Body elongate, rather slender, tapering posteriorly. Parapodial lobes thrown into about four folds. Rhinophores short, stout, cylindrical, directed anterolaterad and slightly curved from base outwardly; beset with low, sharply pointed conical processes. Eyes located at posterolateral base of rhinophores, each surrounded by a white area encircled by a pale brown ring. Foot rounded anteriorly and tapered to blunt point posteriorly; capable of forming broad anterior lobe. Head shield rounded and slightly notched medially. Mouth situated on mid-ventral margin of head shield. Body, head, and foot yellowish white with numerous minute green bodies, apparently commensal algae; yellowish-white ground color of body merging with pale brown of parapodial lobes and of head, which have a reticulum of a darker brown. Margins of parapodial lobes ornamented with small, elongate brown bodies regularly spaced. Inner surface of parapodial lobes next to margin with narrow area of deep orange; beyond this

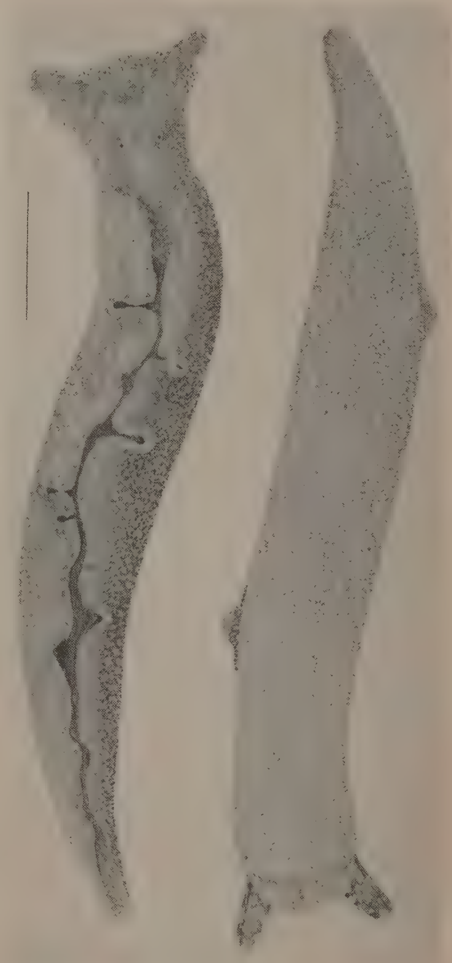
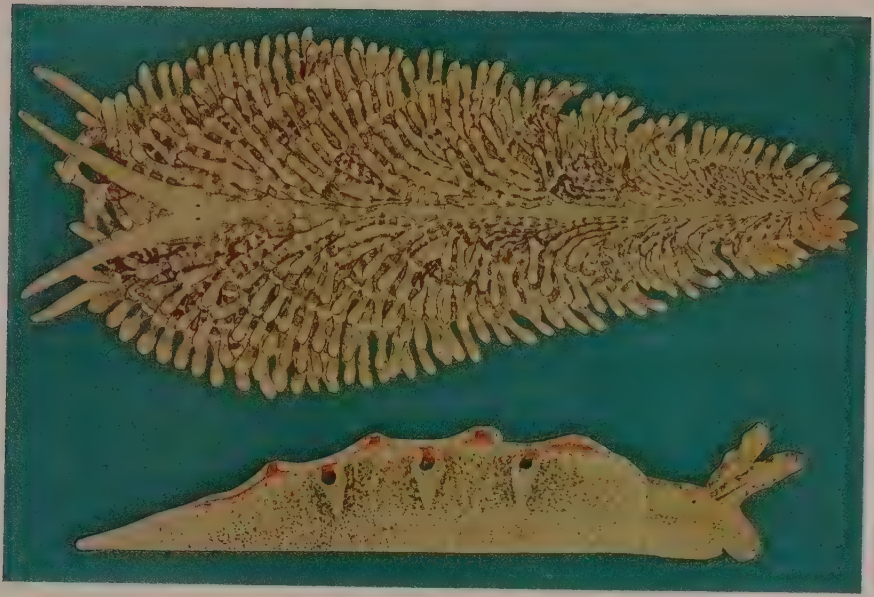
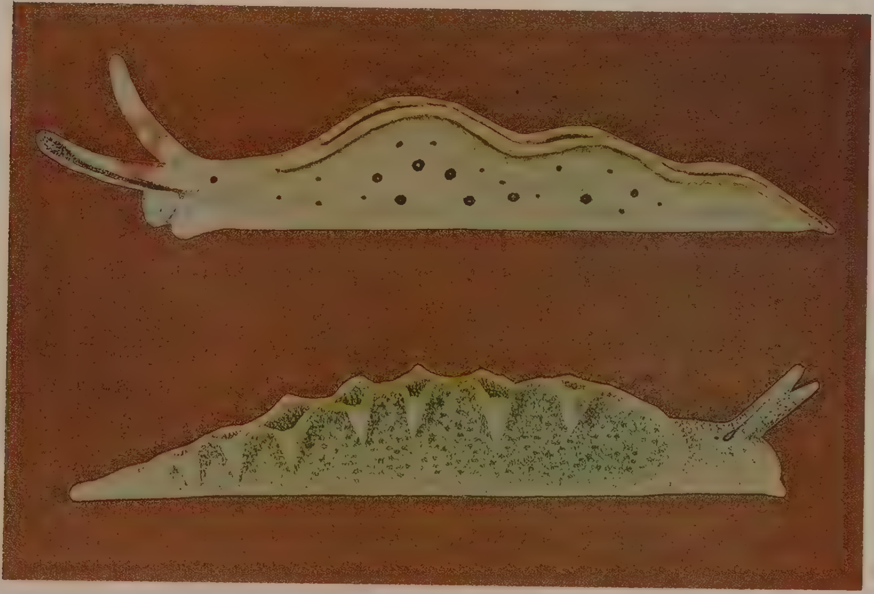


FIG. 10. *Elysia degeneri* n. sp., dorsal and ventral aspects (ca. × 7).

Plate I

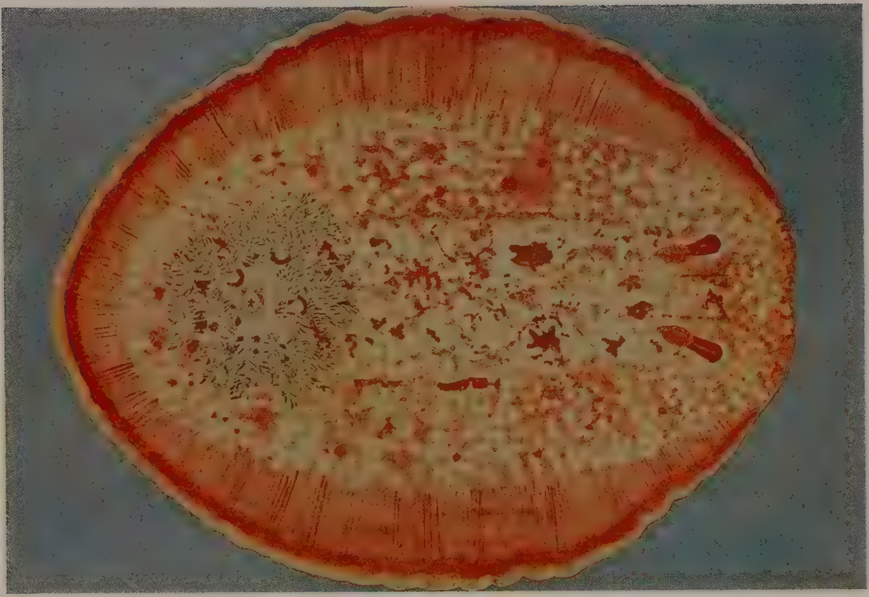


Aeolidia edmondsoni n. sp. (upper), *Elysia degeneri* n. sp. (lower).

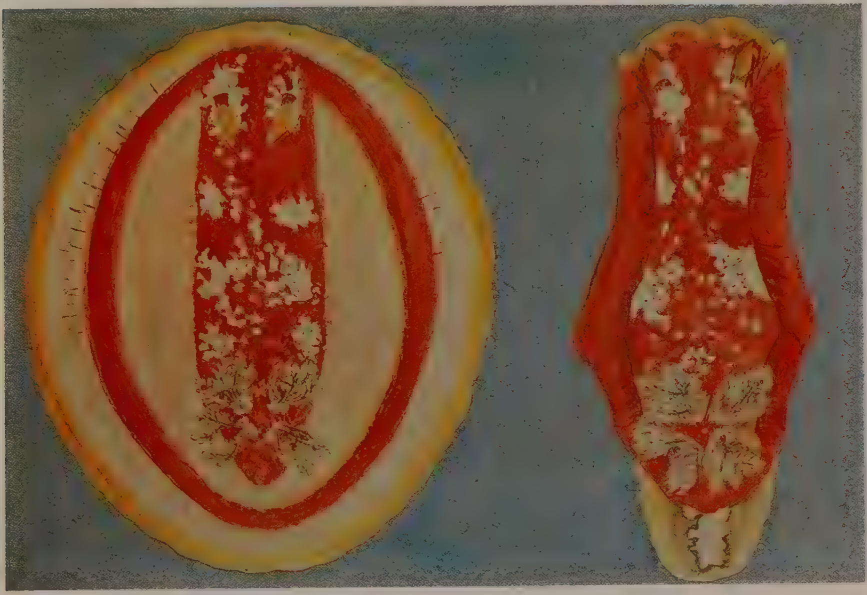


Elysia elsieae n. sp. (upper), *E. nealae* n. sp. (lower).

Plate II



Hexabranchus tinkeri n. sp.



Hexabranchus aureomarginatus n. sp., with mantle spread and closed.

dark green merging into pale green medially.

Length of animal 19 millimeters, width 3 millimeters.

One specimen of this vividly colored little species, designated as the holotype (U.S.N.M. 574929), was found at Waianae, Oahu, March 26, 1923, by Otto Degener, for whom I name the species. Another specimen, 25 millimeters in length, was found at Hanauma Bay, September 12, 1950, by Charles Cutress. This agrees with the type in external characters and coloration, but no algae, which give to the type its distinctive green color, were present. This commensal state may be subject to fluctuation.

Elysia nealae sp. nov.

Fig. 11, Pl. 1

Body slender, elongate, tapering posteriorly. Parapodial lobes intensely folded, medially directed folds meeting dorsally. Rhinophores slender, straight, tapering toward extremities and directed anterolaterad. Eyes prominent, placed at posterolateral bases of rhinophores, each surrounded by a small white area. Foot slightly bilobed with a shallow median notch anteriorly, and tapered to an obtuse point posteriorly. Mouth located at median margin of head shield. Pale green throughout with small white specks and fine concentrated masses of green algae, particularly conspicuous on parapodial lobes. Margin of parapodial lobes and posterior tip of body greenish yellow.

Length of animal 33 millimeters, width 4 millimeters.

One specimen, designated the holotype (U.S.N.M. 574930), was found on seaweeds near the Hawaii Marine Laboratory at Waikiki, November 24, 1923, by Marie C. Neal, for whom the species is named.

This *Elysia* bears some resemblance to *E. degeneri*, but can easily be distinguished from the latter by its long, smooth, tapering tentacles, whereas those of *degeneri* are short, knobbed, and nontapering. The coloration of the parapodial lobes also show a marked distinction. The parapodial lobes of *degeneri* are

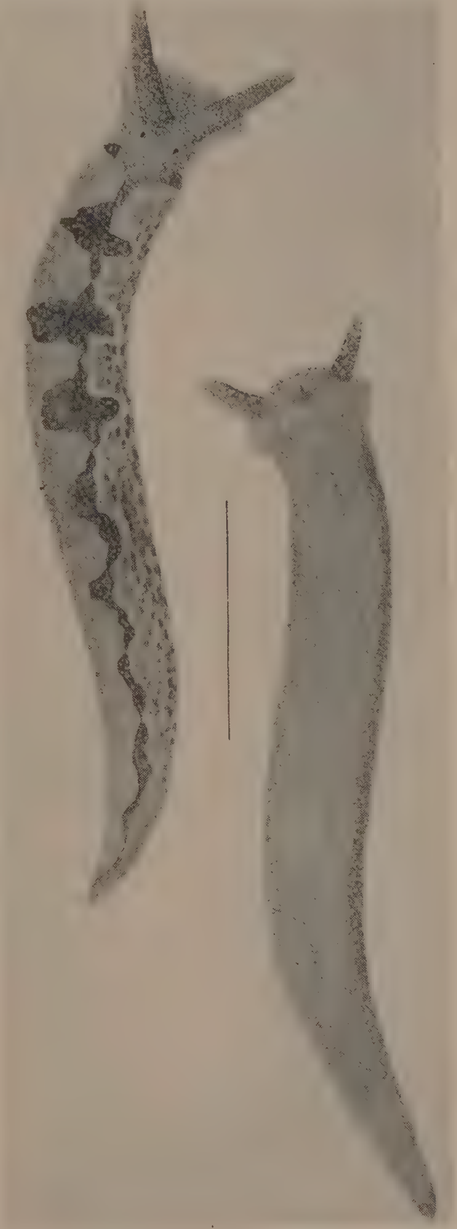


FIG. 11. *Elysia nealae* n. sp., dorsal and ventral aspects (× 4).

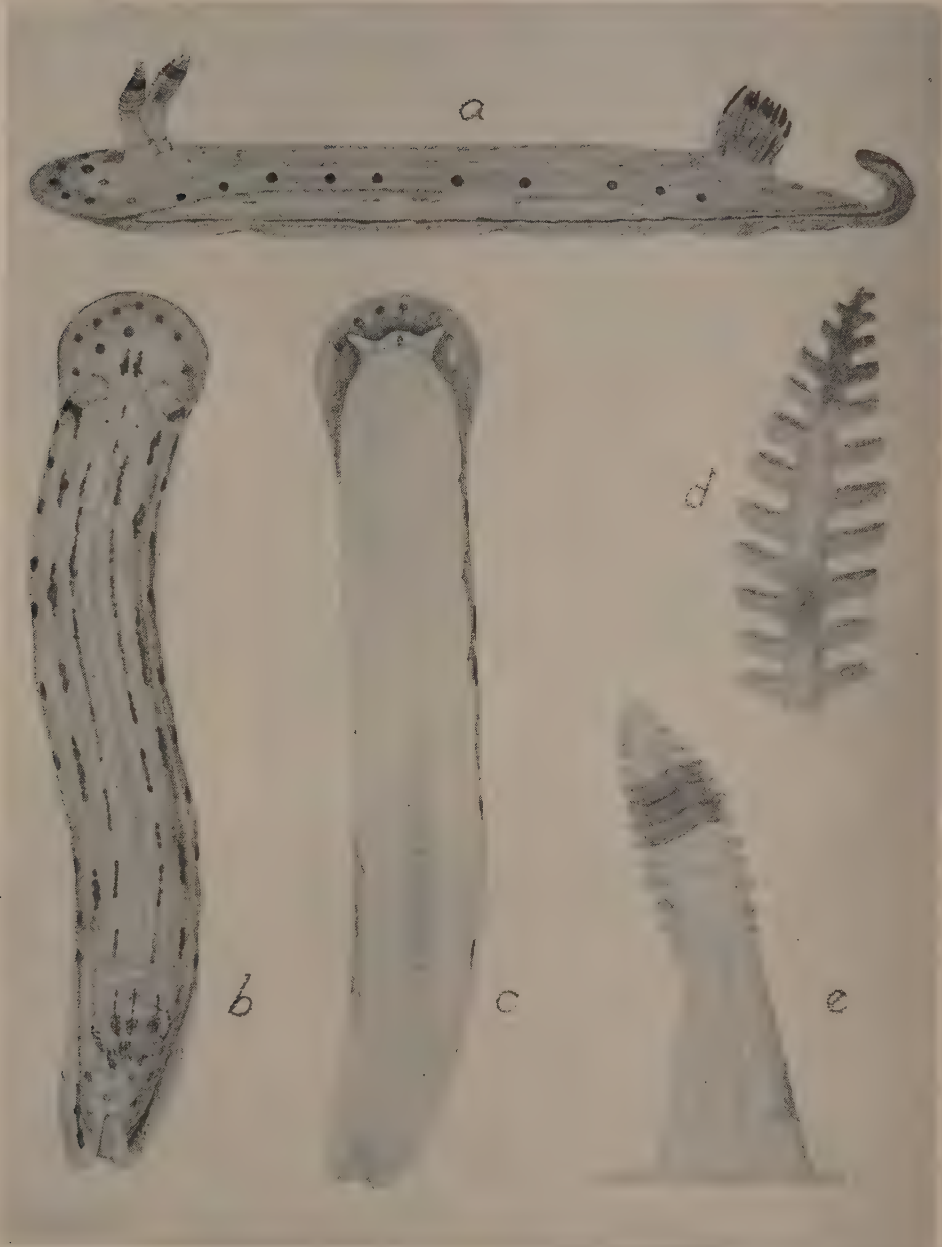


FIG. 12. *Glossodoris prismatica lineata* (Pease). *a*, Lateral aspect; *b*, dorsal aspect; *c*, ventral aspect; *d*, detail of branchia; *e*, rhinophore. (*a*, *b*, *c*, × 8; *d*, *e*, greatly enlarged.)

bordered medially with a bright orange, whereas those of *nealae* are uniformly green.

Glossodoris (=Chromodoris) prismatica lineata (Pease)

Fig. 12

Doris prismatica var. *lineata* Pease, Zool. Soc. London, Proc. 1860: 32.

Body elongate, slender, of equal width from head to branchiae, tapering posteriorly and continuing anteriorly with a broad and rounded head shield. The rhinophores, which are retractile into sheaths with short white collars, are elongate, directed anteriorly and laterally and laminated about half their length with 12 laminae. The branchiae, retractile and surrounded by a low white collar, encircle the vent. They are 9 in number, small, lanceolate, and provided with 10 or 11 thick, spoon-shaped pinnae tapering in size at distal end of the gill. Foot elongate, conforming in width with body, rounded anteriorly, tapering to a point posteriorly, where it may be flexed dorsally beyond the cloak. Eyes minute, located posteromediad of the rhinophores. Oral tentacles short and blunt, directed anterolaterad of mouth. Color light grayish purple with body marked with longitudinal interrupted lines of deep blue; head shield marked dorsally and ventrally with round white and purple spots of equal size and in arrangement conforming to margin of head shield. Row of round purplish spots lining under margin of cloak. Blue line marking dorsal surface of foot near border. Rhinophores light grayish white, encircled with orange band near tip. Branchiae similarly colored, but with orange blotch at tip and near base. Length of animal 17 millimeters.

The specimen on which the above description is based and from which the figures are made was found in March, 1923, near the Hawaii Marine Laboratory at Waikiki, where it was found on a rock in shallow water. Shortly after, two more specimens were brought in from Waianae. Although these agreed closely with the above in size and in nearly all external features, they differed essentially in having 11 gills instead of 9. In the type, described by Pease, 10 gills were present. A similar fluctuation in the number of gills has been reported previously in this family of nudibranchs, hence constancy in number of gills can not be used as a specific character. A variation among individuals within a species is reported by Alder and Hancock (1855) in which the gills of *Doris pilosa* are recorded as varying from 9 to 11 in number. Similar fluctuations in the number of gills within a species has also been observed by Frank M. MacFarland.

Pease's description is here given for comparison:

> Elongate, soft, smooth, convexly rounded above, rather wider posteriorly, portion anterior to the dorsal tentacles somewhat dilated laterally and rounded in front. Branchiae small, erect, lanceolate, pinnate, ten in number, encircling the vent and retractile into a common cavity. Dorsal tentacles elongate, straight, directed forward and laterally, lamillated about two-thirds of their length, and retractile into simple cavities. Foot elongated and projecting much beyond the posterior edge of the body in a point, rounded in front. Colour light greyish-purple, along the back and the remainder of body white, irregular, longitudinal, opaque fine lines on the dorsal region, some of which are confluent. Margins of foot and body beautifully edged with violet. Branchiae whitish and longitudinally striped with orange. Tentacles white, with an orange zone near tip, and a second near the base.
>
> Length 1 inch.

This description fits well in anatomical proportions and in coloring with the specimens at hand, except for lacking the interrupted purple lines and the numerous round purple and brownish dots which are present in my specimens.

A brief description with a figure of the spawn is given in Ostergaard (1950: 109). It is there referred to as *Glossodoris* sp.

Doridopsis macfarlandi sp. nov.

Fig. 13

Body elongate with parallel margins, rounded anteriorly and posteriorly. Cloak soft and devoid of spicules and with margins intensely folded. Rhinophores dark gray with white tips, rather stout, with about 15 lamellae on their distal half; arising from sheaths with slightly elevated simple margins and usually directed slightly anterolaterad. Oral shield light chocolate brown, square with rounded angles, and about half as wide as foot. Branchiae 12 in number, encircling anal papilla and separately retractile within cloak, each with a central stem from which branch and rebranch numerous lateral processes, dark gray. Foot rather narrow, rounded posteriorly, tapering anteriorly, where it is deeply notched and exposes the mouth, dark purplish brown posteriorly and light brown anteriorly with a narrow pale-blue margin, which is bounded anteriorly on its median side by a narrow dark-blue line. Dorsal surface light chocolate brown. Dorsal surface of cloak bluish black with numerous small, round, white spots decreasing in size medially.

Holotype (U.S.N.M. 574931) taken near the Blowhole below Koko Head Crater, Oahu, November 18, 1950, by Donald Strasburg.

Length 3 centimeters, width 12 millimeters. The figure accompanying this description is of a paratype specimen which was found near the Hawaii Marine Laboratory at Waikiki in October, 1922, and which deposited an egg filament in the laboratory.

At intervals this species has been found at the above sites, also at Kawailoa, Oahu. The various specimens agree very closely; but there appear also to be several closely related species, which need to be worked out anatomically in order to separate them.

I have named this species for Dr. Frank M. MacFarland of Stanford University.

The structures of egg filament and veliger larva are figured and described in Ostergaard (1950: 108–109) under *Cryptodoris* sp.

Hexabranchus tinkeri sp. nov.

Fig. 14, Pl. 2

Body depressed, oval in outline when cloak is fully extended. A median area corresponding to the body region proper is variegated with bluish white, yellowish and reddish brown. Surrounding this area is a region of an equal width, softly colored with pale blue and carmine spots and reticulations. Beyond this area is one of similar width—a little narrower posteriorly and interrupted anteriorly—of a pale carmine with radial muscle bands appearing as fine dark-red striae. The cloak is bordered by two narrow bands—an inner dark red and an outer pale carmine—both interrupted anteriorly. Rhinophores elongate, orange, tilted posteriorly. They contain about 40 laminae and are supported by stout carmine stalks, retractile into sockets with low white collars. Branchial plumes, seven in number—three anterior, two lateral, and two posterior—are imperfectly tripinnate and retractile, but not into orifices. They are pink with red ribs. A carmine ring encircles each gill. A conical white anal papilla is situated posterior to the center of the branchial circle. Head small with a pair of deep orange oral tentacles extending from it, with their borders thrown into 8 or 10 intense folds and their greater diameter in lateral directions. The portion of the cloak anterior to the rhinophores is variegated with white, or pale blue, and carmine; dorsal side of foot has similar color which merges into golden at the margin. Foot oblong, rounded at both ends, extended a little beyond cloak when animal is creeping. It is pale flesh with golden margins, which are approximated and crumpled when the animal is swimming. When the animal is at rest, the broad cloak margins are rolled up against the body. Swimming is effected by vigorous transverse flections of the body and undulating movements of the broad, thin cloak, which serves as fins.

The holotype (U.S.N.M. 574926) was found at Waikiki, May 19, 1922, by Robert

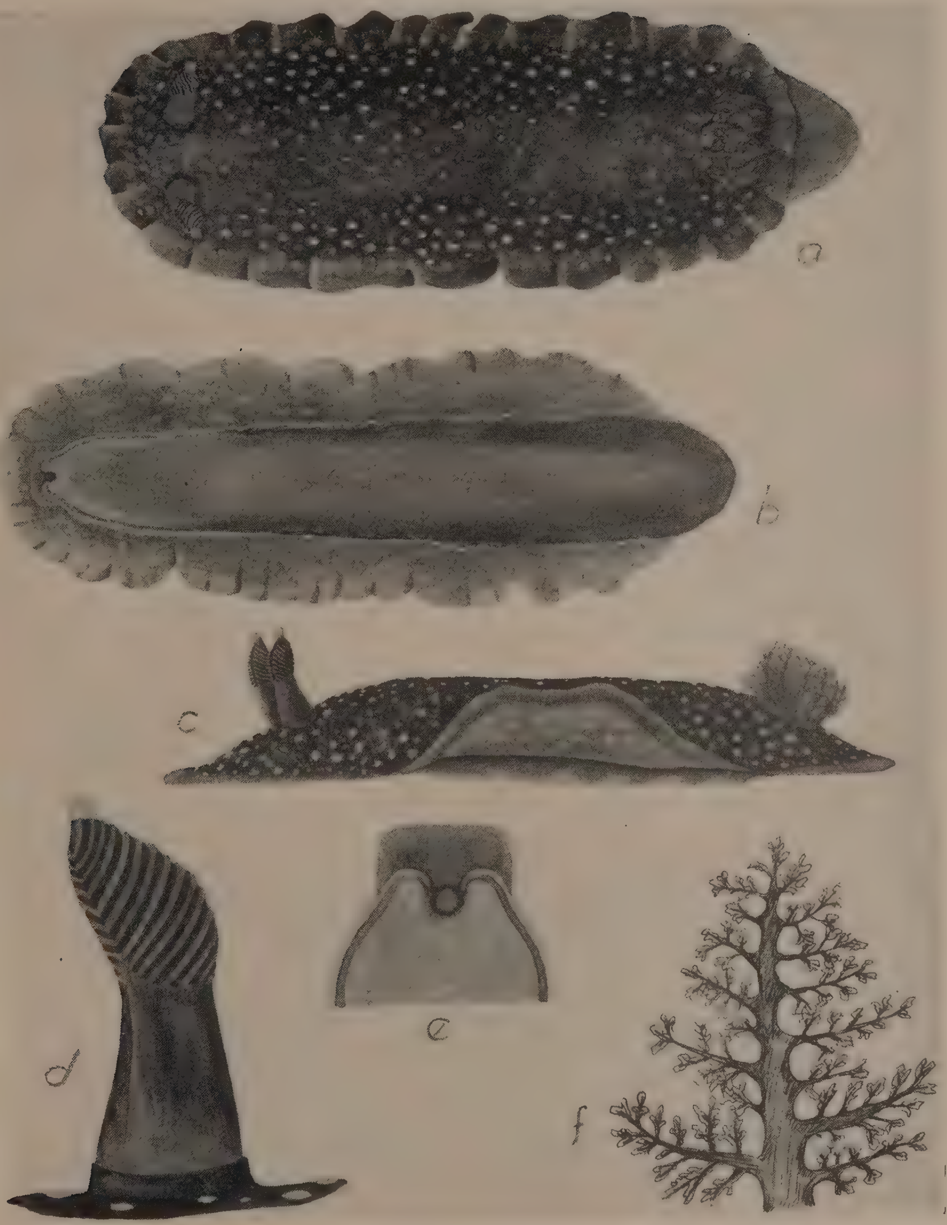


FIG. 13. *Doridopsis macfarlandi* n. sp. *a*, *b*, *c*, Dorsal, ventral, and lateral aspects; *d*, rhinophore; *e*, oral hood and anterior portion of foot; *f*, branchia. (*a*, *b*, *c*, × 3.7; *d*, *e*, *f*, variously enlarged.)

Hope. It measures 13 by 10 centimeters (dimensions of cloak when fully extended). Paratypes bearing the following data are at hand: Nanakuli, Oahu, August, 1950, Charles Cutress; Pearl Harbor, Oahu, October 29, 1949 (2 specimens), June 26, 1950 (1 specimen), July, 1950 (3 specimens, C. Cutress), September 30, 1950 (1 specimen with margin of cloak dark red); on open shore of Oahu, November, 1949; Kailua, Oahu, March 19, 1950; Kahala, Oahu, April 17, 1950.

The largest specimen I have seen (the paratype from Kailua) was 23 centimeters long.

I have named this conspicuous species for Mr. Spencer Tinker, Director of the Honolulu Aquarium, in appreciation of his very generous aid in securing specimens of nudibranchs for me.

The numerous specimens of *H. tinkeri* observed from time to time, and obtained from various parts of Oahu, have shown little variation. However, three specimens obtained from Pearl Harbor during 1950 had a marginal zone of the cloak, 3 centimeters wide, of a deep carmine, darkest near the margin. This zone corresponds to the three outer zones of the type (figured) and, in general, to all other specimens observed. This is probably only a color variation. The gills vary from six to eight in number. When there are six, which appears to be the usual number, they are arranged in a circle around the anal papilla, with three on each side. When seven gills are present, as in the type, one is placed in the median line between the anterior pair of the usual six. But when the animal has eight gills, the posterior gill on each side is represented by two smaller and closely approximated gills. An anomalous deviation from these typical arrangements has also been observed.

Hexabranchus tinkeri is readily distinguished from *H. aureomarginatus*, another Hawaiian species, thus:

Gills large and much branched, 6 or 7 in number; rhinophore sheaths with low, white collars; oral tentacles coarsely scalloped. Color of animal yellowish or white, variegated with carmine or rose; margins of cloak carmine or pink............................ **Hexabranchus tinkeri**

Gills rather small and less branched, 4 to 6 in number; rhinophore sheaths with high collars variegated with white and reddish orange. Oral tentacles intensely scalloped. Color of animal bright orange red variegated with white; margins of cloak white with golden border........................ **Hexabranchus aureomarginatus**

It may also be compared with *Hexabranchus sandwichensis* (Souleyet and Eydoux), from which it differs in coloration and in mode of branching of the gills. Souleyet's specimen was obtained from the Island of Hawaii, and it appears to be rare, since none answering to its description has come under my observation during a period of about 30 years of research in this group.

The description of *H. sandwichensis* is quoted from Souleyet and Eydoux (1852: 451, pl. 25, figs. 1–4).

> *Doris sandwichensis*, nobis.
>
> Cette grande et belle espèce a le corps ovalaire, aplati, more, lisse; le dos d'un blanc bleuâtre sur les côtés, et de couleur violacée sur la ligne médiane, est marqué dans toute son étendue de taches pourprées de différentes grandeurs et irrégulièrement disposées; les bords du manteau très-larges, minces et ondulés, sont d'une belle couleur pourpre, interrompue en dessous par une bande blanchâtre qui entoure le pied et qui se prolonge, en avant, an delà de la bouche et de ses appendices. Les tentacules supérieurs, en form de massue et lamelleux à leur sommet, sont également d'une couleur pourpre trè-Foncée. Les appendices buccaux sont large, à bords onduleux et comme frangés. Le pied, de couleur Jaunâtre, a à peine la moitié de la largeur du corps; ses bords sont minces et ondulés comme ceux du manteau. Les branchies forment huit arbuscules disposés en cercle autour de l'anus; cette ouverture est placée au centre d'un tubercule arrondi et saillant.
>
> Cette *Doris* habit les îles Sandwich; nous l'avans recueillie à Hawaii, la principale des îles de ce groupe.
>
> Sa longueur est de douze à quatorze centimètres.

Doris cardinalis Gould (1852: 302, pl. 25, figs. 397a–b) differs from *H. tinkeri* and *H. aureomarginatus* particularly in the oral tenta-

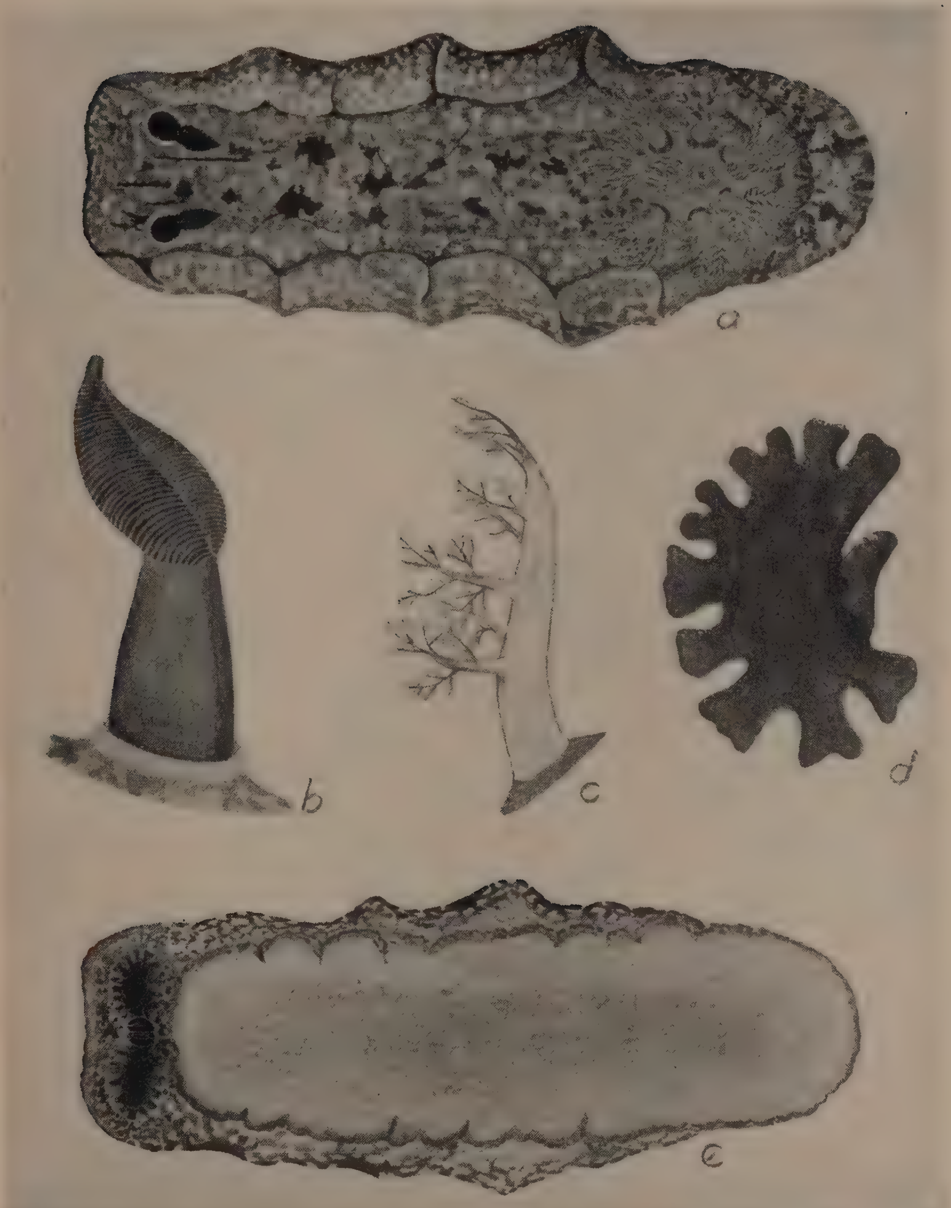


FIG. 14. *Hexabranchus tinkeri* n. sp. *a*, Dorsal aspect; *b*, rhinophore; *c*, branchial plume; *d*, oral tentacle; *e*, ventral aspect. (*a*, *e*, natural size; *b*, *c*, *d*, enlarged.)

cles, which in *Doris cardinalis* are bilobed, but in the two species here described are multilobular.

Hexabranchus aureomarginatus sp. nov.

Fig. 15, Pl. 2

Body much depressed, oval in outline when cloak is fully extended. Cloak wide and very thin at edges, serving as swimming lobes. A median dorsal area, corresponding to the body region, is bright red with groups of fine white flecks, some of which are concentrated to form large spots of irregular outline. Lateral to this area is one of pale rose, interrupted anteriorly, but continued posteriorly by a narrow connection with a corresponding area of the opposite side. Marginal region consisting of three rather narrow uninterrupted color zones: innermost bright red; middle white with radially disposed muscle bands; outermost golden yellow. Rhinophores long and stout, with about 40 golden laminae and with basal stems of reddish orange with a white blotch posteriorly at base of laminated portion; issuing from elevated collars which are variegated with bright red and white and bordered with a narrow golden band. Branchial plumes six, golden with violet stems, retractile, and arranged in a circle around the low anal papilla, the two posterior pairs being closely united at their bases. Head small, usually concealed; from it a pair of oval, golden, leaf-like tentacles with intensely folded borders extend laterally, their long axes directed laterally. Foot oblong and narrowed toward its truncate ends, extending beyond cloak posteriorly when animal is creeping, color beneath, yellow with golden border. A long dark blotch may appear at its center with the viscera showing through. Dorsally the foot is greenish yellow with lighter borders and with a white blotch on its median part near the posterior extremity. The ventral side of the body bordering on the foot is pinkish white; laterally the colors correspond to those of the dorsal surface.

Length of holotype, when fully extended, 76 millimeters, width 65 millimeters.

Though smaller than many other specimens seen, this specimen was chosen for the holotype as its coloration is typical of the species. It was found off the Hawaii Marine Laboratory at Waikiki, within wading distance of the shore, February 2, 1922, by Robert Hope (U.S.N.M. 574927).

Paratypes: 1 specimen, Mokuleia, Oahu, May 22, 1950; 1 specimen, found in reef pool 1 foot deep, Hauula, Oahu, July 1, 1950, Mrs. Pauline Piltz; 2 specimens, near Elks Club, Waikiki, Oahu, April, 1923.

In the many specimens that have come under my observation over a period of nearly 30 years, I have found a close agreement in essential characters, such as would constitute a good species. While some variation in the intensity of coloring does occur, the only radical departure has been noted on the dorsal surface of the foot. This may vary from a grayish yellow with white markings, to a deep carmine. In all specimens observed, the golden margin of the cloak has been present, which seems a good descriptive character on which to base the name of the species.

Most specimens have been found at Waikiki, where they may be seen swimming, or at rest on coral. Swimming is effected, as in *H. tinkeri*, by vigorous flexings of the body and undulations of the cloak margins. When the animal is at rest, the margins of the cloak are rolled up against its sides.

A fluctuation in the size of the gills is found in some specimens, the middle pair being smaller than the others. The largest animal seen was found at Lanikai, Oahu, February 12. It measured 17 by 15 centimeters.

The reproductive orifices, as in *H. tinkeri*, are located on the right side of the body, about one fourth the length from the anterior end, near the junction of the foot. The conspicuous eversible penis is partly embraced on its posteromedial side by the semicircular female orifice. Copulation takes place as follows: two individuals unite with heads turned

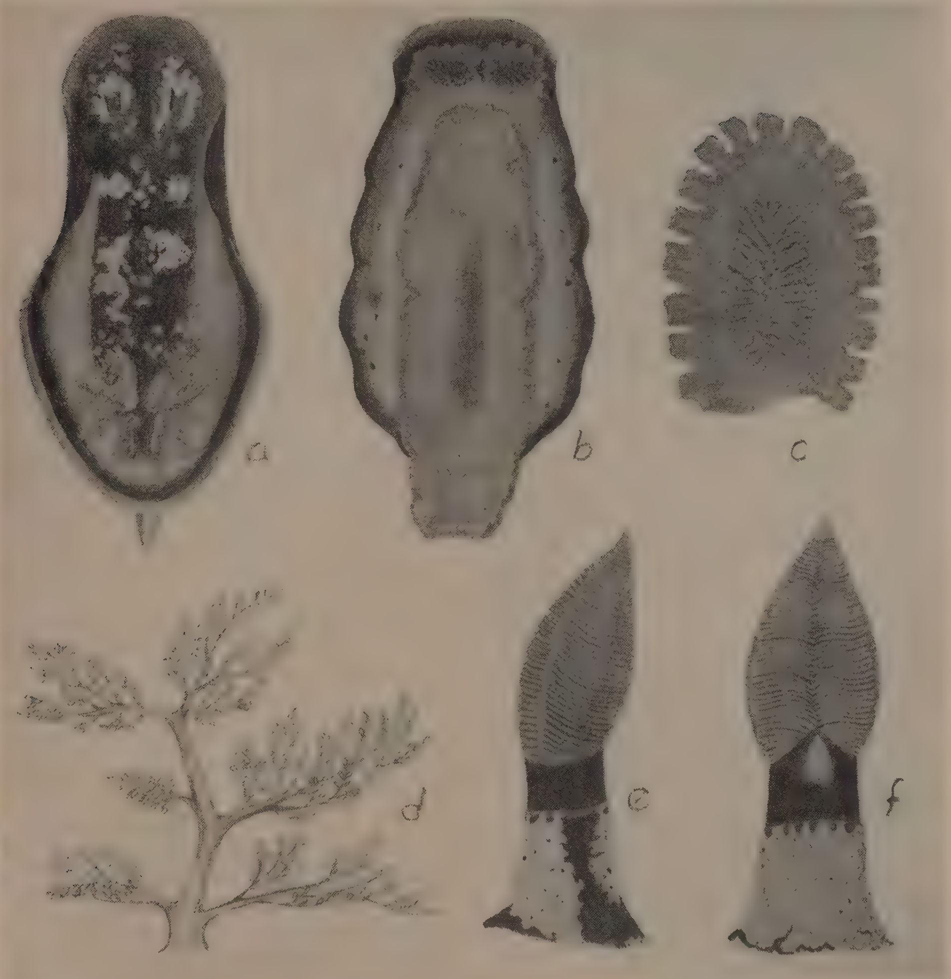


FIG. 15. *Hexabranchus aureomarginatus* n. sp. *a*, *b*, Dorsal and ventral aspects; *c*, oral tentacle; *d*, branchial plume; *e* and *f*, anterolateral and caudal aspects of rhinophore. (*a*, *b*, natural size; *c*, *d*, *e*, *f*, greatly enlarged.)

in opposite directions and with right sides of the anterior ends of their bodies in contact so as to effect a reciprocal exchange of sperm.

The egg structure consists of a flat bright-orange or scarlet ribbon attached by one edge to the substratum and wound around several times. It is referred to as *Hexabranchus* sp. in Ostergaard (1950: 109–110).

Aeolidia edmonsoni sp. nov.
Fig. 16, Pl. 1

Body elongate pyriform, truncate anteriorly, tapering to a point posteriorly. Rhinophores moderately long, linear, smooth, tapering toward extremities and uniting at bases; pellucid pale green with opaque white flecks.

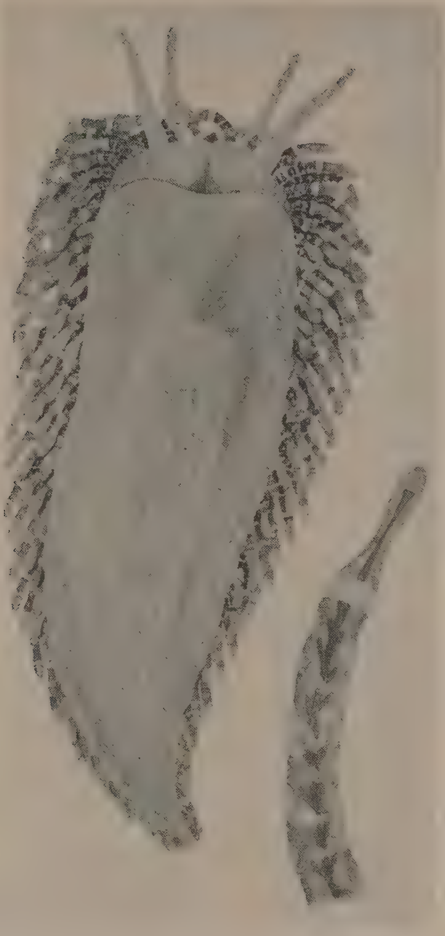


FIG. 16. *Aeolidia edmondsoni* n. sp., ventral aspect (× 5.6) and papilla (greatly enlarged).

Oral tentacles a little shorter than rhinophores, more pointed, of same color, arising anterolaterally on dorsal surface of oral shield near its margin. Oral shield broad, as wide as foot, rounded anteriorly. Branchial papillae numerous and arranged in crowded obliquely transverse rows, which fall away gracefully from the middorsal line in a posterolateral direction. There are 12 or 13 rows, each containing about 14 on the anterior half of the body, the number gradually decreases posteriorly, to only a few very small ones. The papillae are flattened and have many elevations and other irregularities on their proximal portions, and terminate distally in a nipple tipped with canary yellow. At the base of the nipple there is usually a collar of opaque white, and various tubercles of the same color occur over the proximal portion, otherwise pellucid. The central body (probably a liver process) of the papilla is olive green with numerous stubby branches, and terminates abruptly at the yellow cap of the nipple. In reduced light the papillae appear to be brownish or olive green, in normal light they are conspicuously transparent. Foot transparent white, rather broad, truncate anteriorly with rounded obtuse angles, tapering posteriorly from middle of body to a point. Yellowish viscera appearing through mid-region, and branchial papillae clearly visible through thin margins of foot. Mouth appearing on ventral side of oral shield as a longitudinal slit partly concealed by anterior margin of foot. Narrow middorsal region of body exposes between branchial papillae a pale pelucid green with minute white flecks similarly to rhinophores and oral tentacles. Eyes, minute and close together, located posterior to base of rhinophores. Cardiac swelling located in middorsal region between branchiae, about one third the distance from anterior end of body.

Length of body 25 millimeters, greatest width 12 millimeters.

The holotype (U.S.N.M. 574932), which is here described and figured, was found in shallow water near the Hawaii Marine Laboratory at Waikiki in April, 1922, by C. H. Edmondson. Two more specimens were found the following year near the Elks Club, Waikiki. The animals were on a living colony of the coral *Porites compressa*, on the polyps of which they appeared to feed. Many of their egg structures were also attached to this coral.

A description and figures of spawn and veliger stage are given in Ostergaard (1950: 110), referred to as *Aeolidia* sp.

I have named this species for Dr. C. H.

Edmondson for his generous aid in securing specimens.

Melibe pilosa Pease

Fig. 17

Melibe pilosa Pease, Zool. Soc. London, Proc. 1860: 34.

The description by Pease fits so closely the specimen I have figured thàt it is quoted here:

> Elongate, smooth, widest anteriorly, and tapering to a point behind. Sides convexly rounded, and the back arched. Foot linear, grooved, extending the whole length of the body, and acute at both ends. Six pairs of thick tuberculated lobes along the back, the anterior pair opposite, the others alternate to one another, the last at the tip of the body. These lobes are easily deciduous, contracted at their bases, truncated above, convex outside, and flattened on the inner surface. Frontal veil very large, semi-globular, much inflated above; united beneath the head, forming a continuous margin, which is closely fringed. Mouth proboscidiform, and the orifice vertical. Tentacles on the posterior portion of the veil rather remote, small, ovate, closely and transversely lamellated and retractile into long trumpet-shaped sheaths, which are furnished with laciniated appendages. Everywhere with small, soft, branched, tentacular processes. Colour fawn, subtranslucent, more or less crowded with whitish, which, under the lens, has the appearance of minute dots. Body punctured with brown, which are most conspicuous along the flanks. Tubercles on the lobes brown. Foot pale.
>
> Length 2½ inches.
>
> These animals were found among seaweed, in the upper region of the laminarian zone, and when placed in a basin of water were very active, swimming by suddenly curving the head and tail laterally, so as nearly to touch one another. When slightly disturbed they could cast off one or all of their lobes. The length of their lobes varies much, being in some as large again as in others; they may be consequently reproduced, after being cast off. Their foot cannot be used for creeping on a flat surface, but is well adapted for clasping sea-weed.

The above description of the habits of the animal agrees with my observation based on a considerable number of specimens found on the reefs near shore along leeward Oahu, principally at Waikiki and Kahala. Specimens have been found in September, February, June, and December.

The specimen of *M. pilosa* that I have figured measures 3 centimeters in length. Other specimens reached the length of 5 centimeters, thus approching the size of Pease's "2½ inches" (6 cm., 3 mm.).

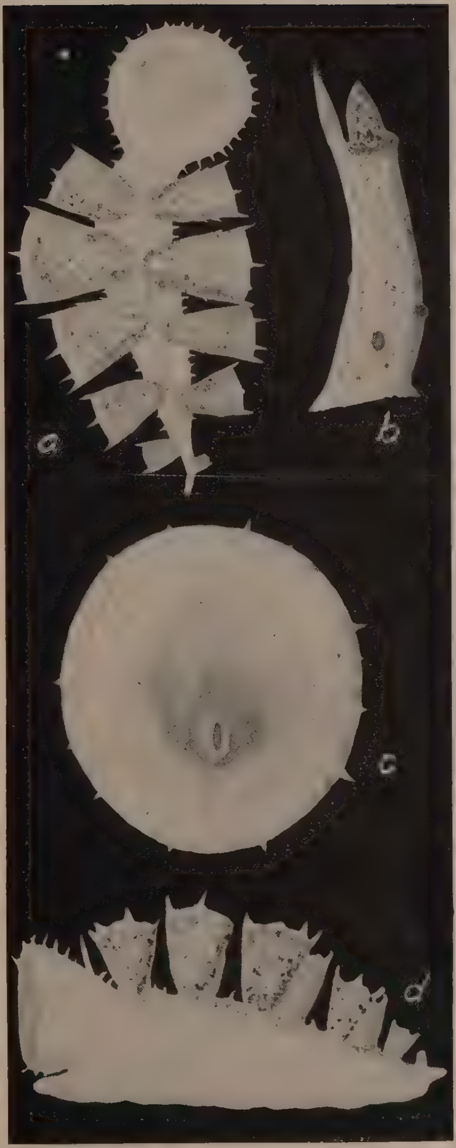


FIG. 17. *Melibe pilosa* Pease. *a*, Dorsal aspect; *b*, detail of tentacle; *c*, oral aspect of frontal veil; *d*, lateral aspect. (*a*, *d*, × 2.4.)

While several of the animal's habits have been described by Pease, its feeding habit might also be mentioned as one of interest. The large oral veil is opened widely and placed with its free margin against a smooth surface; whereupon the slender marginal tentacles, aided by the constriction of the veil, gather the food particles (diatoms, etc.) to the mouth at the dorsoposterior wall of the velum.

A description of the spawn and the veliger shell with illustrations is given in Ostergaard (1950: 111).

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15

A Revision of the Surgeon Fish Genus *Ctenochaetus*, Family Acanthuridae, with Descriptions of Five New Species[1]

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(Plates I & II; Text-figures 1-3)

The genus *Ctenochaetus* is distinguished from other surgeon fish genera chiefly by its unique teeth, which are numerous, loosely attached in the jaws and very elongate, with expanded incurved tips. Little difficulty is experienced in assigning specimens to this genus; however, insufficient attention has been given to identification at the species level. Two specific names, *striatus* Quoy & Gaimard and *strigosus* Bennett, have been applied indiscriminately. Generally only one or the other name is used and some authors have asserted their belief that the genus is monotypic. In this paper the validity of *C. striatus* and *C. strigosus* is established and five other species are described as new.

Several species of *Ctenochaetus* are very abundant in the tropical inshore waters of the Pacific and Indian Oceans and the genus is extensively recorded in the literature. Many records are listings of names only and others contain too little descriptive information to provide identification. Such records have been omitted, generally, unless the specimens reported on were examined by me.

Drawings of adults of only two of the seven species are given. The others have either been pictured previously or present insufficient differences in external appearance from remaining species to warrant the preparation of figures. The shape of the teeth (principally the number of denticulations on the lateral edge of the expanded tips) has been found to be the most important basis for the separation of species. Text-fig. 1 consists of drawings of the teeth of all seven species. The number of teeth (Text-fig. 2) and fin ray and gill raker counts (Tables 1-3) are also of diagnostic value.

It is with pleasure that I acknowledge the guidance and assistance given by Leonard P. Schultz, Ernest A. Lachner and Robert H. Kanazawa of the United States National Museum, where much of the work on this paper was done. William A. Gosline of the University of Hawaii provided helpful counsel, and thanks are due Boyd W. Walker of the University of California at Los Angeles and George S. Myers of the Stanford Natural History Museum for the loan of specimens.

The types of the new species are deposited in the United States National Museum.

Methods of Counting and Measuring

Each ray of the dorsal and anal fins with a distinct base was counted regardless of how close adjacent rays might be. In cases where two rays branch from a common base, they were counted as one. At times dissection was necessary to determine whether the last two rays originate from a single basal element. Pectoral fin ray counts include the two uppermost unbranched rays, the first being a very short bony spicule. Few gill raker counts were made, because it is difficult to remove a complete gill arch from an acanthurid without damaging the specimen. The gill rakers are small and occur in two distinct series, anterior and posterior (actually more medial on the arch than posterior). All rakers (including rudiments) in each series were counted separately. In many instances it was not possible to determine which raker occupied the position at the angle of the arch, therefore

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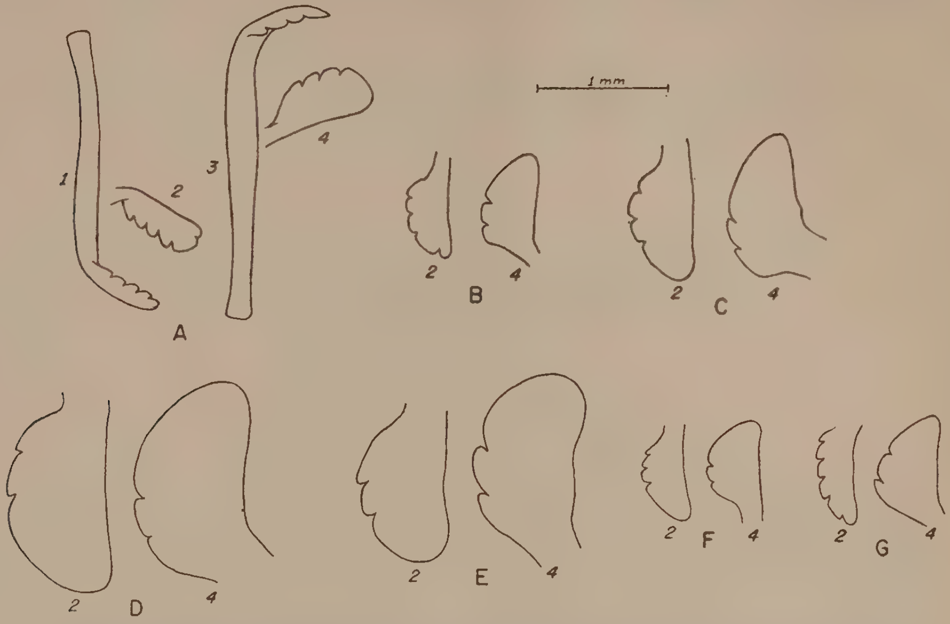
[1] Contribution No. 58, Hawaii Marine Laboratory, in co-operation with the Department of Zoology and Entomology, University of Hawaii.



Text-fig. 1. Camera lucida drawings of the teeth of *Ctenochaetus*. **A.** *striatus*, 141 mm. specimen, Marshall Islands. **B.** *strigosus*, 119 mm. specimen, Hawaiian Islands. **C.** *cyanoguttatus*, type. **D.** *hawaiiensis*, type. **E.** *magnus*, type. **F.** *tominiensis*, type. **G.** *binotatus*, type. **1.** lateral view of upper tooth. **2.** inner view of end of upper tooth. **3.** lateral view of lower tooth. **4.** inner view of end of lower tooth. All of the teeth were taken from the left side of the jaw near the center of the mouth.

only the total count is recorded. Occasional specimens showed a fusion of rakers on the dorsal end of the medial series where the rakers normally become broad, low ridges; no counts from such specimens are included in the table. At least for *C. striatus*, no obvious increase in gill raker counts occurs with increasing size after the fish have completely transformed from the late postlarval or acronurus stage. The state of being completely transformed is easily distinguished by the presence of fully formed scales on the body.

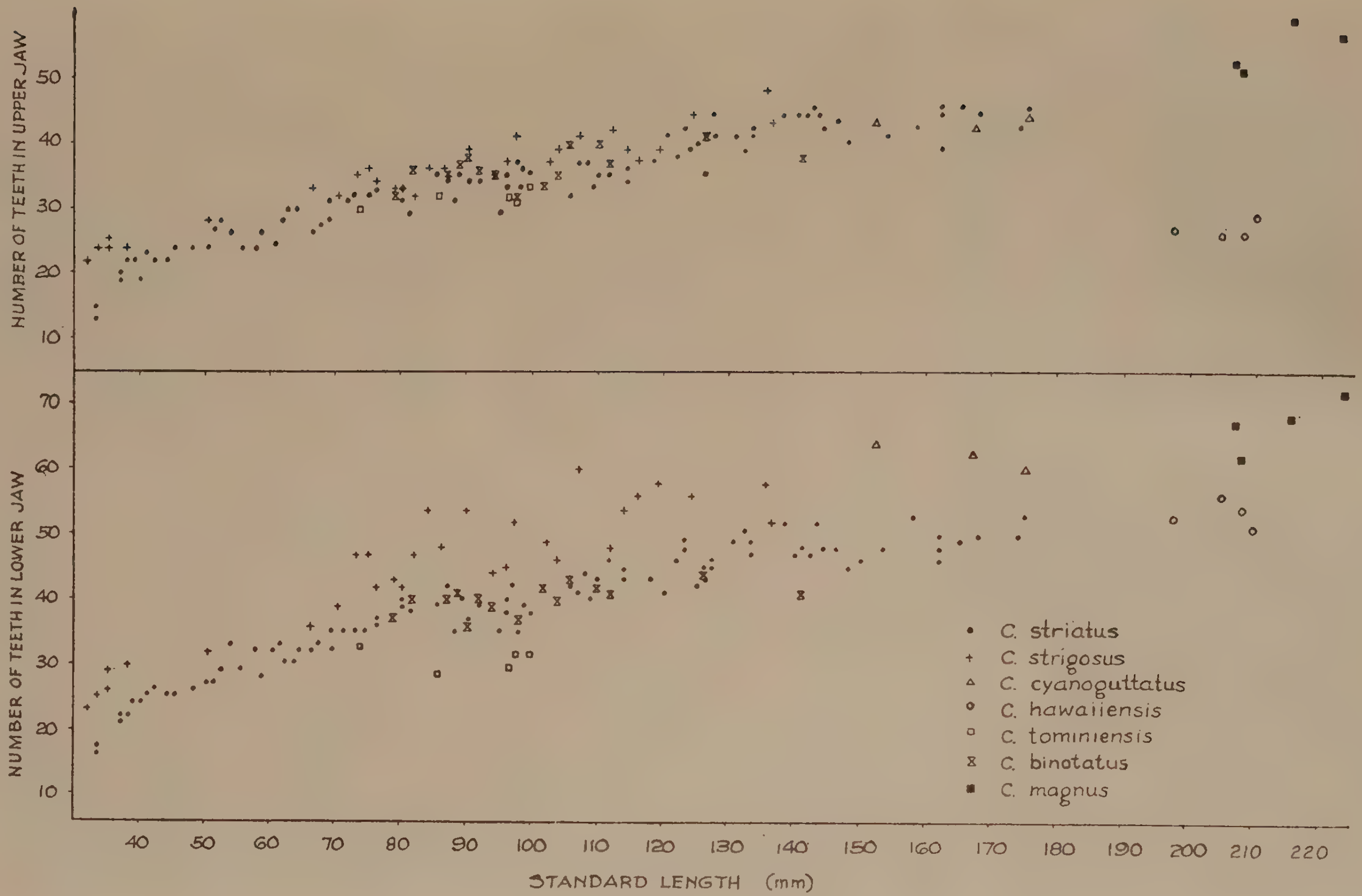
The standard length was measured from the tip of the snout to the posterior end of the hypural plate. Head length was taken from the tip of the snout to the most posterior part of the opercular membrane. Body depth is the distance from the natural groove at the base of the second anal spine to a similar groove at the base of the dorsal fin. Caudal concavity is the distance between vertical lines passing through the tips of the shortest middle caudal ray and the longest ray of the dorsal lobe of the caudal fin. Proportional measurements are based on specimens above 70 mm. in standard length.

Counts of the number of teeth were not made in specimens with tightly closed or damaged jaws. Even the best specimens generally had missing teeth; however, these were detected by empty sockets in the gums and by gaps in the series and were included in the total counts.

The number of teeth was found to increase with increasing size in *striatus* and *strigosus*. Text-fig. 2 represents a graph of the relationship between the number of teeth and the standard length of these two species. Such data from the available specimens of the other five species are also included in the graph, but there are not enough of these of different lengths to clearly show this relationship.

Scale counts are difficult to make, for the scales are small and not in even rows. Approximate scale counts are recorded as the number of vertical scale rows from the upper end of the gill opening to the posterior end of the caudal peduncle spine.

In the description of new species, data in parentheses are referable to paratypes. Proportional measurements and counts of scales were made on five paratypes, if available, including the largest and smallest specimens. Fin ray counts are based on all paratypes. Tooth counts



TEXT-FIG. 2. Tooth counts of *Ctenochaetus*.

and gill raker counts of paratypes may be found in Text-fig. 2 and Table 3, respectively.

Genus CTENOCHAETUS Gill

Ctenodon Klunzinger, Synopsis der Fische des Rothen Meers, 1870: 509 (proposed as a subgenus; preoccupied by *Ctenodon* Wagler 1830).

Ctenochaetus Gill, Proc. U. S. Nat. Mus., **7**: 279. 1885 (Type species, *Acanthurus strigosus* Bennett).

Quoy & Gaimard (1824) described and figured the first species of this genus as *Acanthurus striatus*. They remarked on its unusual dentition. E. T. Bennett (1828) named another, *Acanthurus strigosus*, from Hawaii, and he accurately described the teeth. Although Günther (1861) separated two of the species, *strigosus* and *ctenodon* Cuvier & Valenciennes, in a key on the basis of dentition, he left them in *Acanthurus*. Gill (1884) established the genus *Ctenochaetus*, designating *A. strigosus* Bennett

TABLE 1. COUNTS OF THE SOFT RAYS OF THE DORSAL AND ANAL FINS FOR SPECIES OF *Ctenochaetus*

Species and locality	Dorsal soft rays								Anal soft rays							
	24	25	26	27	28	29	30	31	21	22	23	24	25	26	27	28
striatus																
Wake I.					3	6	4						2	6	4	1
Marshall Is.				1	14	39	8					1	3	34	23	1
Gilbert Is.				1	9	13	4	1				1	5	21	1	
Line Is.					2	1	1						1	2	1	
Phoenix Is.					2	2	1						1	3	1	
Samoa Is.					4	9	1	1						7	7	1
Tuamotu Arch.						2	7	2						6	5	
Society Is.						3	4						1	1	5	
Austral Is.							1								1	
Solomon Is.					2	1								3		
New Hebrides					1	1								1	1	
Palau Is.					1	1								1	1	
Mariana Is.					5	8	11	4					1	5	16	6
Philippine Is.				12	24	14						3	23	22	2	
Formosa					2									2		
East Indies				2	2	3							2	4	1	
Egypt, Red Sea					3	2							4		1	
Mauritius				2	2	2	1						3	2	2	
Madagascar							1								1	
strigosus																
Hawaiian Is.		4	19	23	1						9	32	6			
Johnston I.			8	1							2	6	1			
Tuamotu Arch.			4						1	1	1	1				
Philippine Is. & East Indies		3	6	4							7	6				
Mauritius			1								1					
cyanoguttatus, sp. nov.																
Gilbert Is.				2									2			
Phoenix Is.					1								1			
Cocos I.					1								1			
hawaiiensis, sp. nov.																
Hawaii				1	3								3	1		
magnus, sp. nov.																
Malden & Jarvis I.				3								2	1			
Cocos I.			1									1				
tominiensis, sp. nov.																
Celebes	1	5								4	2					
binotatus, sp. nov.																
Philippine Is. & Molucca Is.	2	4	16	8						1	9	17	3			

TABLE 2. COUNTS OF PECTORAL FIN RAYS FOR THE SPECIES OF *Ctenochaetus*

Species and locality	Pectoral fin rays 15	16	17
striatus			
Marshall, Mariana, and Samoa Is.		6	29
Philippine Is. and East Indies		15	24
Egypt, Red Sea		3	4
Mauritius		3	1
strigosus			
Hawaiian Is.	1	22	
Philippine Is.		13	
Mauritius		1	
cyanoguttatus, sp. nov.			
Gilbert, Phoenix, and Cocos Is.		1	3
hawaiiensis, sp. nov.			
Hawaii		4	
magnus, sp. nov.			
Malden, Jarvis, and Cocos I.		1	3
tominiensis, sp. nov.			
Celebes	2	4	
binotatus, sp. nov.			
Philippine and Molucca Is.	3	27	

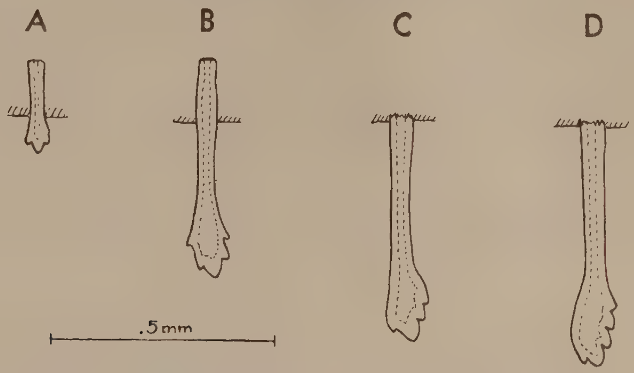
as the type species. He was apparently unaware of *A. striatus* Quoy & Gaimard. Prior to Gill, Klunzinger (1870) set up *Ctenodon* as a subgenus for *strigosus* and *ctenodon*. This was not the *Ctenodon* of Swainson (1839), the type species of which was *Acanthurus sohal* (Forskål), and possibly not of Bonaparte (1833) (for which there was no description nor type specified). However, Wagler's use in 1830 of *Ctenodon* for a reptile invalidates subsequent generic use of this name.

Ctenochaetus is characterized as follows: body compressed, elliptical, the depth contained 1.7 to 2.2 in standard length; head length 3 to 3.8 in standard length; caudal peduncle armed on each side by a single, sharp, folding spine; length of caudal peduncle spine 2.3 to 4.3 in head length; least depth of caudal peduncle 1.9 to 2.7 in head length; mouth small, terminal, and only slightly protractile; jaws equal; teeth numerous, in a single series in each jaw, movable, elongate, with tips expanded, incurved, and denticulate on the lateral margin; eye diameter contained about 3 to 5 times in head length; interorbital space 2.6 to 3.3 in length of head; gill openings restricted to the sides; gill membranes confluent and attached to the isthmus; scales ctenoid, very small, and not in regular rows; head scaled, though not conspicuously; lateral line complete; dorsal fin single, continuous, unnotched, with 8 spines, the first small and easily overlooked; dorsal soft rays 24 to 31; anal fin with 3 spines, the first very short, and 21 to 28 soft rays; the first 2 to 6 dorsal and anal soft rays unbranched; pectoral fins long, their length contained 2.7 to 3.2 in standard length; pectoral rays 15 to 17; pelvic fins I, 5, relatively long and pointed, and only slightly posterior in their insertion to the base of the pectoral fins; caudal fin with 16 principal rays and varying in shape from lunate to nearly truncate; 22 vertebrae; stomach subspherical to oval with very thick walls.

The single erectile spine on each side of the caudal peduncle is a prominent feature of four of the acanthurid genera, *Acanthurus, Ctenochaetus, Paracanthurus* and *Zebrasoma*. The latter genus differs from the other three in having 4 or 5 dorsal spines instead of 7 to 9. The monotypic *Paracanthurus* is readily separable with its pelvic count of I, 3 and its remarkable coloration. *Ctenochaetus*, as noted, is distinguished primarily by its unusual dentition. Usually the genus has 8 dorsal spines (in counts of over 300 specimens two had 9 and three had 7 dorsal spines). In the 28 species of Indo-Pacific *Acanthurus* the usual count of dorsal spines is 9. Two species, *A. pyroferus* Kittlitz and *A. sohal* (Forskål), have 8 and another, *A. nubilus* (Fowler & Bean), has 6 or 7.

Ctenochaetus striatus and certain other species of this genus are similar in general body shape and color pattern to *Acanthurus nigroris* Cuvier & Valenciennes (=*Hepatus atramentatus* Jordan & Evermann, 1905, and *Acanthurus lineolatus* Günther, 1873). The similarity may be seen even in the transforming acronurus stages of these fishes by comparing Fig. A (*C. striatus*) and Fig. C (*A. nigroris*) in Plate 62 of Schultz & Woods (1953). Other *Acanthurus* species such as *lineatus* and *sohal* may be striped in the postacronurus form, but the stripes do not angle downwards as they pass posteriorly on the body. Inconsistent with the apparent close relationship of *Ctenochaetus* to *A. nigroris* is the finding that the roundish, heavy-walled stomach of the former does not resemble the elongate, thin-walled stomach of *A. nigroris* but rather that of such acanthurids as *A. olivaceus* and *A. gahhm.*

Although no existing *Acanthurus* species may be considered the direct progenitor of the genus *Ctenochaetus*, it seems reasonable to conclude (as has Aoyagi, 1943) that *Ctenochaetus* was derived from *Acanthurus*-like stock. This view is supported by the fact that postlarval *Ctenochaetus* have teeth much like those of postlarval *Acanthurus*, and these transform into the typical adult *Ctenochaetus* dentition (see Text-fig. 3 and discussion under *striatus*).



Text-fig. 3. A. Upper tooth of 27 mm. acronurus larva of *Ctenochaetus strigosus*. B to D. Upper teeth from 31 mm. postacronurus stage of *Ctenochaetus striatus*. Dotted lines indicate margins of pulp cavity.

The food habits and method of feeding of *Ctenochaetus strigosus* were investigated. The stomach contents of seven adult specimens from different localities in the Hawaiian Islands were analyzed. All but one fish contained a very large amount (up to 90%) of fine inorganic sediment; the remaining detrital material was mostly algal, consisting of diatoms and small fragments of many kinds of red, green and blue-green algae. About 1 to 2 per cent was soft, unidentifiable organic matter. There were occasional tiny molluscs and crustaceans, sponge spicules, holothurian plates, pedicellaria fragments, etc. The stomach of one specimen was filled primarily with a fine red alga (*Ceramium* sp.), though there was still a large amount of sediment. When a thallus of fine filamentous red algae (*Polysiphonia* sp.) was placed in an aquarium containing two adult specimens of *strigosus*, the fish attempted to feed upon it. Their slender movable teeth, not able to effectively bite off pieces, soon became tangled in the algae, resulting in very little being ingested. When fine particles of the alga were put in the tank and allowed to settle, the fish fed in the following manner: the body was elevated to a near-vertical position about 15 mm. above the bottom, there was a pause, then the fish pecked at a small area, the teeth and lips scraping over the surface. Such an area was not only cleaned of particulate algae but also of very fine sediment that had collected there, suggesting that a suction mechanism is involved as well as a scraping one. There was definitely no lateral plowing or sieving action by the teeth as their comb-like structure might suggest. Sand on the bottom was generally avoided, but if picked up, most was usually forcefully ejected.

Key to the Species of Ctenochaetus

1a. No prominent blackish spot at base of last 3 to 7 rays of both the dorsal and anal fins. (Juvenile and young adult *striatus* have a small black spot basally at rear of dorsal fin only).

  2a. Teeth of the upper jaw with 4 to 7 denticulations (including tip) on lateral edge of their distal expanded ends.

    3a. Teeth of the upper jaw with 5 to 7 denticulations on lateral edge of their distal expanded ends; body with numerous pale longitudinal stripes (often faint or not visible in preserved specimens); spots, if present, occur only on head or anterior part of body; inter-radial membranes of pectoral fin hyaline; length of longest dorsal ray contained 3.6 to 4.4 times in standard length.

      4a. Teeth of upper jaw with 6 denticulations (rarely 5 or 7); teeth of lower jaw with 4 denticulations (including tip); caudal fin lunate, caudal concavity (see section on methods of measuring and counting) contained 3.7 to 6 times in standard length; body depth contained 1.9 to 2.3 in standard length; dorsal fin rays VIII, 27 to 31 (usually 28 to 30); anal fin rays III, 24 to 28 (usually 25 to 27) . . . . *Ctenochaetus striatus* (Quoy & Gaimard).

      4b. Teeth of upper jaw with 5 denticulations; teeth of lower jaw with

3 denticulations (including tip); caudal fin moderately concave, caudal concavity contained 5.7 to 10 times in standard length; body depth contained 1.7 to 2.0 in standard length; dorsal fin rays VIII, 25 to 28 (usually 26 or 27); anal fin rays III, 21 to 25 (usually 23 or 24)........ *Ctenochaetus strigosus* (Bennett).

3b. Teeth of upper jaw with 4 denticulations on lateral edge of their distal expanded ends; body without stripes, when alive speckled with numerous bright blue spots which may or may not persist as pale spots in preserved specimens; inter-radial membranes of pectoral fin dark brown; length of longest dorsal ray contained about 5.2 times in standard length...... *Ctenochaetus cyanoguttatus*, sp. nov.

2b. Teeth of upper jaw with 3 denticulations (including tip) on lateral edge of their distal expanded ends.

5a. Ratio of number of teeth in lower jaw to number in upper jaw about 2:1; caudal fin slightly emarginate, caudal concavity contained 18 to 40 times in standard length; longest dorsal ray contained 4 to 5 times in standard length; inner surfaces of lips plicate, margins crenulate; distance from base of upper lip to distal end of upper teeth contained 3.1 to 3.7 times in head length; length of snout contained 3.6 to 3.9 in standard length......... *Ctenochaetus hawaiiensis*, sp. nov. (Plate II, Fig. 2)

5b. Ratio of number of teeth in lower jaw to number in upper jaw about 1.2:1; caudal fin lunate, caudal concavity contained 6 to 7 times in standard length; longest dorsal ray contained 5.5 to 6 times in standard length; inner surfaces and margins of lips smooth; distance from base of upper lip to distal end of upper teeth contained 4.5 to 5.3 times in head length; length of snout contained 4.1 to 4.8 in standard length.... *Ctenochaetus magnus*, sp. nov.

1b. A prominent blackish spot at base of last 3 to 7 rays of both the dorsal and anal fins, these spots extending narrowly on adjacent regions of caudal peduncle.

6a. Membranes of caudal fin and posterior parts of dorsal and anal fins pale; margins of lips papillate; enlarged distal curved portions of each tooth of upper jaw with lower half smooth and blade-like and upper half with 3 (rarely 2) lateral denticulations ... *Ctenochaetus tominiensis*, sp. nov.

6b. Membranes of caudal, dorsal, and anal fins dark brown; margins of lips smooth; enlarged distal curved portion of each tooth of upper jaw divided into 6 approximately equal lateral denticulations .... *Ctenochaetus binotatus*, sp. nov.

CTENOCHAETUS STRIATUS (Quoy & Gaimard)

Text-fig. 1 A; Plate I, D-F; Text-fig. 3 B-D

Acanthurus argenteus Quoy & Gaimard, Voy. *Uranie*, Zool.: 372, pl. 63, fig. 2. 1824 (Guam); Cuvier & Valenciennes, Hist. Nat. Poiss., **10**: 239. 1835.

Acanthurus striatus Quoy & Gaimard, Voy. *Uranie*, Zool.: 373, pl. 63, fig. 3. 1824 (type locality, Guam); Cuvier & Valenciennes, Hist. Nat. Poiss., **10**: 229. 1835 (not Hawaiian Is.); ?Günther, Cat. Fish. Brit. Mus., **3**: 334. 1861 (Borneo).

Acanthurus ctenodon Cuvier, Règne Animal., **2**: 224. 1829; Cuvier & Valenciennes, Hist. Nat. Poiss., **10**: 241, pl. 289, 1835 (Caroline Is. and New Guinea); Günther, Cat. Fish. Brit. Mus., **3**: 342. 1861 (Ceylon and East Indies); Bleeker, Ned. Tijdschr. Dierk., **1**: 156. 1863 (Halmahera); Playfair, Fishes of Zanzibar: 57. 1866 (Zanzibar) (as variety *a*); Day, Proc. Zool. Soc. London: 688. 1870 (Andaman Is.).

?Acanthurus flavoguttatus Kittlitz (not of Herre, 1936, or Fowler, 1944), Mus. Senckenb., **1**: 193, pl. 13, fig. 5. 1834 (Caroline Is.).

?Acanthurus Ketlitzii Cuvier & Valenciennes, Hist. Nat. Poiss., **10**: 222. 1835.

Ctenodon Cuvierii Swainson, Nat. Hist. Class. Monocard. Animals **2**: 256. 1839.

Acanthurus strigosus Cuvier & Valenciennes (not of Bennett), Hist. Nat. Poiss., **10**: 243. 1835 (New Guinea); Bleeker, Nat. Tijdschr. Ned. Indië, **4**: 264. 1853 (New Guinea, not Hawaiian Is.); *ibid.*, **6**: 102. 1854 (East Indies); ?Günther, Cat. Fish. Brit. Mus., **3**: 342. 1861 (New Guinea, not Hawaiian Is.); Kner, *Novara* Exped. Fische, **1**: 211. 1865-1867 (Tahiti); Günther, Journ. Mus. Godeffroy, **2** (3): 116, pl. 79. figs. B and C. 1873 (Indo-Pacific); Day, Fishes of India, **1**: 207, pl. 47, fig. 2. 1876 (Andaman Is.);—Fauna Brit. India, **2**: 143. 1889 (India); Hardenburg, De Tropische Natuur, **22**: 155, fig. 1. 1933.

Acronurus argenteus Günther (in part), Cat. Fish. Brit. Mus., **3**: 346. 1861 (Marianas).

Acanthurus (*Ctenodon*) *ctenodon* Klunzinger, Synops. Fische Rothen Meeres: 509. 1871 (Red Sea).

Acanthurus (*Ctenodon*) *strigosus* Klunzinger, Fische Rothen Meeres, **1**: 85. 1884 (Red Sea); Weber, *Siboga* Exped. Fische, **57**: 319. 1913 (Indo-Australian Arch.).

Ctenochaetus strigosus Seale, Occ. Pap. B. P. Bishop Mus., **1**: 109. 1901 (Guam); Fowler & Ball (in part), B. P. Bishop Mus. Bull., 26: 19. 1925 (Wake I., not Hawaiian Is. or Johnston I.); Herre, Philipp. Journ. Sci., **24**: 438, pl. 15, figs. 2 and 3. 1927 (Philippine Is.); Fowler (in part), Mem. B. P. Bishop Mus., **10**: 247. 1928 (Oceania, not Hawaiian Is.); Fowler & Bean (in part), Bull. U. S. Nat. Mus.,100, **8**: 200. 1929 (Philippine Is. and East Indies); Herre, Field Mus. Nat. Hist. Zool. Ser., **21**: 247. 1936 (Polynesia and East Indies); Fowler, Acad. Nat. Sci. Phila. Mon., 2: 76, 147, 173, 185, 202, 215. 1938 (Marquesas Is., Society Is. and Christmas I. in the Line Is.); Poll, Mus. Roy. Hist. Nat. Belgique, **18**: 11. 1942 (Society Is.); Aoyagi, Coral Fishes: 218, pl. 6, fig. 20 (teeth only). 1943 (Riu Kiu Is.); Schultz (in part), U. S. Nat. Mus. Bull., 180: 161. 1943 (Phoenix and Samoa Is.); Hiyama, Poisonous Fishes South Seas: 83, pl. 19, fig. 52. 1943 (Marshall Is.); Smith, Sea Fishes S. Africa: 240, pl. 33, fig. 614. 1949 (Natal); de Beaufort, Fishes Indo-Aust. Arch., **9**: 128, fig. 24. 1951 (Indo-Pacific, not Hawaiian Is.); Harry, Atoll Res. Bull., 18: 150. 1953 (Raroia, Tuamotus).

Ctenodon ctenodon Fowler, Journ. Acad. Nat. Sci. Phila., **12**: 545. 1904 (Sumatra).

Ctenochaetus striatus Jordon & Seale (in part), Bull. Bur. Fish., **25**: 355. 1906 (Oceania, not Hawaiian Is.); Seale, Occ. Pap. B. P. Bishop Mus., **4**: 67. 1906 (Society Is., Cook Is., New Hebrides, Austral Is. and Solomon Is.); Evermann & Seale, Bull. Bur. Fish., **26**: 97. 1907 (Zamboanga, P. I.); Kendall & Radcliffe, Mem. Mus. Comp. Zoöl., **35**: 145. 1912 (Manga Reva); ?Jordan, Tanaka & Snyder, Cat. Fishes Japan: 634. 1913 (Misaki and Sagami, Japan); Fowler & Bean, Proc. U. S. Nat. Mus., **62**: 57. 1922 (Zamboanga, P. I.); Fowler, Proc. Acad. Nat. Sci. Phila., **75**: 42. 1923 (Madagascar); Herre, Philipp. Journ. Sci., **34**: 437, pl. 13, fig. 2. 1927 (Philippine Is.);—Field Mus. Nat. Hist. Zool. Ser., **21**: 246. 1936 (Tuamotus and Moorea); Schultz & Woods, U. S. Nat. Mus. Bull., 202: 620, pl. 61, fig. A, pl. 62, figs. A and B. 1953 (Marshall and Mariana Is.).

Teuthis striatus Barnard, Ann. S. Afric. Mus., **21**: 780. 1927 (Natal).

?*Ctenochaetus ctenodon* Whitley, Journ. Pan-Pacific Res. Inst., **3**: 12. 1928 (Santa Cruz Is.); Whitley & Colefax, Proc. Linn. Soc. New S. Wales, **63**: 294. 1938 (Nauru).

Diagnosis.—No black spot at axil of both dorsal and anal fins; teeth of upper jaw with 6 denticulations, of lower jaw 4, on lateral edge of expanded tips; membranes of pectoral fin hyaline; caudal fin lunate, caudal concavity 3.7 to 6 in standard length; dorsal soft rays usually 28 to 30.

Description.—Dorsal rays VIII, 27 to 31; anal rays III, 24 to 28; pectoral rays 16 or 17; anterior gill rakers 27 to 36; posterior gill rakers 29 to 42; scales from gill opening to posterior end of caudal peduncle spine 104 to 122.

Body depth 1.9 to 2.3, snout 4.2 to 4.8, pelvic fin 3.3 to 3.7, eighth dorsal spine 4.9 to 5.8, longest dorsal ray 3.6 to 4.4, third anal spine 5.4 to 6.7, longest anal ray 4.4 to 5.2, caudal concavity 3.7 to 6, all in standard length.

Margins and inner surfaces of lips smooth. Upper teeth with lateral edge of distal expanded end with 6 (rarely 5 or 7) denticulations. Lower teeth with 4 lateral denticulations at end (a small fifth one is sometimes evident).

Color in alcohol dark brown with numerous pale lengthwise slightly irregular lines on body (which are often faded and difficult to see); median fins brown; traces of about 5 lengthwise bands may at times be seen in the soft dorsal and anal fins; pectoral fin with rays light brownish (except uppermost principal ray which is edged in dark brown) and membranes hyaline; pelvic fins brown; young specimens may show a small black spot at the base of the last few dorsal rays. Color of juveniles dark brown with 8 to 12 pale longitudinal stripes on the body about ⅓ as

TABLE 3. COUNTS OF GILL RAKERS FROM THE FIRST GILL ARCH FOR THE SPECIES OF *Ctenochaetus*

Species and locality	Anterior series of gill rakers																						
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
striatus																							
Marshall, Mariana and Samoa Is.										1	1	3	5	4	4	3	1						
Philippine Is. and East Indies										3	5	6	3	1									
Egypt, Red Sea									1	2	1												
Mauritius											2	3	1	1									
strigosus																							
Hawaiian Is.										1	2	2	2	2	2								
Philippine Is.								2	1	1	1	1											
cyanoguttatus, sp. nov.																							
Gilbert and Phoenix Is.							1		1	1													
hawaiiensis, sp. nov.																							
Hawaii				2		2																	
magnus, sp. nov.																							
Malden, Jarvis, and Cocos I.									3	1													
tominiensis, sp. nov.																							
Celebes	1	3																					
binotatus, sp. nov.																							
Philippine Is.				1	2	1	2	2	2	1													
	Posterior series of gill rakers																						
striatus																							
Marshall, Mariana and Samoa Is.												1		1		2	3	4	4	4	2		1
Philippine Is. and East Indies										1		1	1	2	3	2	4	3	1				
Egypt, Red Sea										1	2		1										
Mauritius													1	2	1	2	1						
strigosus																							
Hawaiian Is.											1	4	4	2									
Philippine Is.									1	3	1	1											
cyanoguttatus, sp. nov.																							
Gilbert and Phoenix Is.															1	1		1					
hawaiiensis, sp. nov.																							
Hawaii						1		2	1														
magnus, sp. nov.																							
Malden, Jarvis, and Cocos I.																1	3						
tominiensis, sp. nov.																							
Celebes	4																						
binotatus, sp. nov.																							
Philippine Is.			1		4	1	3	2															

broad as intermediate brown areas, which angle slightly downward as they pass posteriorly. At a standard length from 50 to 65 mm. the number of pale lines is suddenly doubled by the appearance of thin whitish lines in the center of the brown intermediate areas; these narrow lines become as broad as the pale lines of the first set, and more lines are added above and below, especially above, until the adult number of about 30 to 40 is attained. The ones added above the original set tend to angle upwards.

Color in life dark olive brown with blue lengthwise lines on the body and small orange spots on the head and nuchal region; soft dorsal and anal fins with about 5 lengthwise dark bluish lines; pectoral fin yellowish.

Juvenile specimens from the Gilbert Islands of about 40 mm. length were observed with the first set of pale lines red in color, narrow light bluish lines in the intermediate brown areas, and red tips to the lobes of the caudal fin. It is this color pattern that Herre (1927) probably tried to show in his Figure 2 of Plate 13 and which led him into the mistaken and persistent contention that this juvenile form was a different species. The error is an easy one to make in view of the variability in length at which adult coloration and configuration are assumed.

One specimen in the acronurus stage (transparent with silvery abdomen) was secured by night lighting at anchorage at Sydney Island in the Phoenix Islands by personnel of the Pacific Oceanic Fishery Investigations. This specimen, USNM No. 163616 and 32 mm. in standard length, is shown in Plate I, D. It is interesting to note that there is already a change-over taking place from larval dentition to adult-type dentition even though there is no evidence of any other bodily transformation to adult form. This change in dentition may be seen in only a slightly more advanced state in the transforming specimen of Plate I, E, from which the three teeth in Text-fig. 3 B to D were drawn. These teeth were all taken from the upper jaw of this specimen and show early stages in the transformation of tooth form. The inward bending of the expanded tips, already apparent in C, can only be seen in a side view of the teeth. The tooth drawn in A of Text-fig. 3 was taken from the *strigosus* acronurus of Plate I, D. All of its teeth are essentially alike; there are about 18 in each jaw. Probably this specimen is in an earlier stage of development than the *striatus* acronurus of Plate I, D. It is suspected that the teeth of *striatus* younger than the latter will bear 3 denticulations like the *strigosus* acronurus. The *striatus* acronurus has about 18 upper teeth and 16 lower teeth with more apparent just beneath the gums at the ends of the jaws. The lateral teeth are more adult-like in form than more medially-located teeth. The most striking thing about the dentition was the finding, upon dissection, of good-sized adult-type teeth imbedded in the soft tissue within the bones of the jaws. Five were found from one side of the upper jaw just above the upper teeth and six from one side of the lower jaw just below the lower teeth. Only the most medial of these imbedded teeth showed a departure from the *Ctenochaetus* pattern, for not all of the denticulations of this tooth were restricted to the lateral side. Subsequent dissection of the premaxillary and dentary bones of juvenile and adult specimens of *C. striatus* and other *Ctenochaetus* of all sizes showed these teeth to be present, in greater number and larger size in larger specimens, and it is believed that they function as replacement teeth. Specimens of species of *Acanthurus,* including acronurus and postacronurus forms, were examined, and adult-type teeth characteristic of this genus were also found imbedded in the bones of the jaws.

Remarks.–C. striatus is an exceedingly abundant and widespread species, probably occuring in the entire tropical Indo-Pacific region except the Hawaiian Islands. Jordan, Tanaka & Snyder (1913) record what is probably this species from Japan. J. L. B. Smith in a letter states that it appears to be the most abundant acanthurid on the reefs of tropical east Africa. At Onotoa Atoll in the Gilbert Islands, after two months of collecting, I found it was the dominant fish on a weight basis among all the reef fishes taken. It was very common on the benched reef slope (Cloud, 1952) of the windward reef of the atoll and about coral heads in the lagoon.

In the Red Sea *striatus* seems to have a lower gill raker count (Table 3) and also a greater percentage of specimens with 17 pectoral rays than 16 (Table 2). More material is needed from the Indian Ocean and Arabian Sea to clarify these and other differences.

Better established is the demarcation on the basis of dorsal and anal fin ray counts (Table 1) between populations in the Philippines and East Indies and the rest of Oceania. Also from the examination of fin ray counts, southeast Oceania (i.e., Society Islands and Tuamotus) may represent a differentiated population.

The largest specimen seen by me was 195 mm. in standard length. It was taken in the Philippines.

Taxonomic Discussion. — In all probability *Acanthurus argenteus* Quoy & Gaimard is a transforming *Ctenochaetus striatus.* These authors suspected that it was the young of some species they had not collected, but the nature of the striped color pattern and the high fin ray counts leave little doubt that it is the same as *striatus*. I retain the name *striatus* because it has been commonly used, whereas *argenteus* has been recognized as a name applying to an immediate postacronurus form (the name referring to the silvery coloration of the abdomen) and has never been applied to any adult surgeon fish.

The consideration of *Acanthurus flavoguttatus* Kittlitz (*A. Ketlitzii* Cuvier & Valenciennes) as a synonym of *C. striatus* is based on the Kittlitz figure which is greenish with yellow spots on the head and yellow lines on the body. Lack of reference to dentition and the peculiar fin ray counts account for the uncertainty in my decision. The type of *flavoguttatus* was not located.

Acanthurus ctenodon Cuvier & Valenciennes was referred to synonymy by Kner (1865) and by Günther (1873).

Much confusion has resulted from the frequent use of the name *strigosus* for the species *striatus*. This seems to stem from Günther (1873) who considered *striatus* the young of *strigosus* and in the overlooking by Gill (1884) of the Quoy & Gaimard species altogether in his erecting of the genus *Ctenochaetus*. Jordan & Evermann (1905) perpetuated the error by copying Günther's plate of *striatus* and using it to represent the common Hawaiian species which, in reality, is *strigosus*. Fowler (1928) did not help by referring *striatus* to the synonymy of *Acanthurus lineatus*.

Herre's (1927) separation of *strigosus* and *striatus* was based on specimens not exceeding 60 mm. in length and is erroneous.

CTENOCHAETUS STRIGOSUS (Bennett)

Plate II, Fig. 1; Text-fig. 1 B; Plate I, A-C; Text-fig. 3 A

Acanthurus strigosus Bennett, Zool. Journ., **4**: 41. 1828 (type locality, Hawaiian Is.); Cuvier & Valenciennes (in part?), Hist. Nat. Poiss., **10**: 243. 1835 (Hawaiian Is., probably not New Guinea); Günther (in part?), Cat. Fish. Brit. Mus. **3**: 342. 1861 (Hawaiian Is., probably not New Guinea).

Acanthurus (*Etenodon*) *strigosus* Steindachner, Denkschr. Akad. Wiss., **70**: 495. 1901 (Honolulu).

Ctenochaetus strigosus Jenkins, Bull. U. S. Fish. Comm., **22**: 480. 1903 (Honolulu); Snyder, Bull. U. S. Fish. Comm., **22**: 534. 1904 (Honolulu); Fowler & Ball (in part), B. P. Bishop Mus. Bull., 26: 19. 1925 (Laysan, French Frigate Shoals and Johnston I., but not Wake I.); Fowler (in part), Mem. B. P. Bishop Mus., **10**: 274. 1928 (only Hawaiian Is.); Fowler & Bean (in part), U. S. Nat. Mus. Bull., 100, **8**: 200. 1929 (Philippines and East Indies); Fowler, Mem. B. P. Bishop Mus., **11**: 344. 1931 (Honolulu);—Acad. Nat. Sci. Phila. Mon., 2: 233 (only). 1938 (Honolulu);—Proc. Acad. Nat. Sci. Phila., **93**: 257. 1941 (Honolulu); Whitley, Proc. Roy. Soc. New S. Wales: 23. 1954 (Great Barrier Reef, Australia).

Ctenochaetus striatus Jordan & Evermann, Bull. U. S. Fish. Comm., **23**: 398, (Fig. 174 after Günther, not *strigosus*), 1905 (Hawaiian Is.); Jordan & Jordan, Mem. Carnegie Mus., **10**: 66. 1922 (Hawaiian Is.).

Ctenochaetus flavicauda Fowler, Acad. Nat. Sci. Phila. Mon., 2: 104, pl. 10, fig. 24. 1938 (Takaroa, Tuamotus);—Mem. B. P. Bishop Mus., **12**: 104. 1949 (Takaroa, Tuamotus).

Ctenochaetus sp. Harry, Atoll Res. Bull., **18**: 151. 1953 (Raroia, Tuamotus).

Diagnosis.—No black spot at axil of dorsal or anal fin; teeth of upper jaw with 5 denticulations, of lower jaw 3, on lateral edge of expanded tips; membranes of pectoral fin hyaline; caudal fin moderately concave, caudal concavity 5.7 to 10 in standard length; dorsal soft rays usually 26 or 27.

Description.—Dorsal rays VIII, 25 to 28; anal rays III, 21 to 25; pectoral rays 16 (rarely 15); anterior gill rakers 27 to 34; posterior gill rakers 28 to 33; scales from gill opening to posterior end of caudal peduncle spine 85 to 96.

Body depth 1.7 to 2, snout 4.3 to 4.8, pelvic fin 3.1 to 3.4, eighth dorsal spine 4.8 to 5.5, longest dorsal ray 3.8 to 4.2, third anal spine 5.3 to 6.5, longest anal ray 4.4 to 4.7, caudal concavity 6 to 10, all in standard length.

Margins and inner surfaces of lips smooth; upper teeth with 5 denticulations (occasional teeth from Philippine specimens will show tiny 6th denticulation); lower teeth with 3 denticulations (including tip).

Color in alcohol brown with about 35 narrow pale bluish longitudinal lines (about ¼ as broad as the alternate brown bands) on the body which angle upwards on the basal part of the dorsal fin and downwards on the basal part of the anal; small pale spots on the head (and anteriorly on the body in Philippine specimens); a pale ring, broader posteriorly, around the eye in Hawaiian and Tuamotu specimens, restricted to the posterior edge of the eye in Johnston Island material, and absent in Philippine specimens; median fins brown (except caudal fin of Tuamotu specimens which is abruptly pale, white in life); pectoral fin pale except edge of uppermost principal ray which is almost black; pelvic fins brown.

Color in life from a 35 mm. kodachrome transparency of a Hawaiian specimen brown with narrow pale blue longitudinal lines on the body and basally on dorsal and anal fins; purplish region on chin; blue spots on head; yellow ring around eye; caudal fin brown; pectoral fin rays brownish, membranes orange-yellow; pelvic fins brown.

Hawaiian specimens in life show considerable variation in ground color. Some, especially in a light-colored environment (as areas of high coral cover), become a light tan in color. Others may be dark brown. The ground color of the species at Raroia, Tuamotus, was observed by Harry (1953) to be black.

Remarks.—Along with the color differences noted above, and meristic data, differences in the shape of the caudal fin may be seen among the specimens from the Philippines and East Indies, Hawaiian Islands, Johnston Island, Tuamotus and Mauritius which might form the basis for the recognition of subspecies when more material is available and the range of the species more completely known. The single specimen from Mauritius has the least concave caudal fin, the caudal concavity being contained in the standard length about 20 times. The caudal concavity of specimens from the Philippines and the Hawaiian Islands is 7 to 10. Johnston Island specimens have a caudal concavity which ranges from 5.7 to 9 in the standard length; Tuamotu specimens have the most lunate caudal fins, the caudal concavity contained about 5.7 times in the standard length.

Harry (1953) reported acute pain and swelling in the hand and arm when cut on the hand by the caudal spine of this species in Raroia; the pain did not subside until the second day and persisted for a week. He added that the only other surgeon fish he encountered producing such effects was *C. striatus* (recorded as *strigosus*), though pain from this species lasted only 3 to 4 hours and was not so intense. I tested the poisonous qualities of the caudal spine of Hawaiian *strigosus* by gingerly inserting the tip of the spine into my palm; a stinging sensation was soon experienced, and the experiment was carried no further.

This species is extremely abundant in the Hawaiian Islands where it is known by the local name Kole. Elsewhere, except perhaps Johnston Island, it is not at all common. Only 13 specimens from the Philippines, Moluccas and Celebes were found at the U. S. National Museum among the vast collections made by the *Albatross* Philippine Expedition (1907-1910); only four are known from the Tuamotus, and one from Mauritius. The single specimen from the Great Barrier Reef was identified by Whitley with the aid of a manuscript key such as appears in this paper and was recorded from Australia by him (1954).

Although more collecting in the Indo-Pacific region may reveal new localities for *strigosus*, it is believed that it is not in continuous distribution throughout its range. The differentiation which has taken place in five of its known localities supports this contention. The great abundance of this species in Hawaii stands in sharp contrast to its apparent absence from much of the Indo-Pacific and its scarcity in the few areas where it does occur. This may be associated with the absence of *striatus* from the Hawaiian Islands.

The acronurus specimen (Plate I, A), U.S.-N.M. 118040 and 27 mm. in standard length, was taken at night from the steamer *Albatross* at the surface at Diamond Head Light, Oahu, Hawaiian Islands, on May 6, 1902. The transforming specimen of Plate I, B (University of Hawaii No. 1877) was collected by W. A. Gosline on the reef at Diamond Head, Oahu, May 16, 1950. It is 28 mm. in standard length. The recently transformed juvenile (Plate I, C), U.S.N.M. 167199, was taken by the author at a depth of 40 feet, Waikiki, Oahu, on June 4, 1952. As no small juveniles have been seen in tidepools or very shallow water, it is suspected that the acronurus transforms to the juvenile stage at a moderate depth on the reef. Postacronurus and juvenile *striatus*, on the other hand, occur in immense numbers in tidepools and protected shallow-water areas.

The largest specimen of *strigosus* seen by me, 139 mm. in standard length, was collected by the *Albatross* Philippine Expedition at Luzon.

The food habits of this species are discussed in the general section on the genus.

CTENOCHAETUS CYANOGUTTATUS, sp. nov.

Text-fig. 1 C

?*Acanthurus guttatus* Kittlitz (not of Bloch & Schneider), Mus. Senckenb., **1**: 193, pl. 13, fig. 4. 1834 (Luganor I.).

?*Acanthurus marginatus* Cuvier & Valenciennes, Hist. Nat. Poiss., **10**: 221. 1935 (new name for *Acanthurus guttatus* Kittlitz); Günther, Cat. Fish. Brit. Mus., **3**: 333.1861 (Luganor).

?*Acanthurus ctenodon* Var. *b* Playfair, Fishes of Zanzibar, 57. 1866. (Zanzibar).

Ctenochaetus strigosus Snodgrass & Heller, Proc. Washington Acad. Sci., **6**: 402. 1905 (Cocos I., Costa Rica); Schultz (in part), U. S. Nat. Mus. Bull., 180: 161. 1943 (Hull I.).

Ctenochaetus sp. Hiyama, Poisonous Fishes South Seas: 92, pl. 19, fig. 53. 1943 (Marshall Is.).

Holotype.—U.S.N.M. No. 167178, Aunteuma Island, Onotoa Atoll, Gilbert Islands, lee side, depth of water about 5 feet in poorly-defined surge channel region, August 1, 1951, spear, John E. Randall, 170.5 mm. in standard length.

Paratypes.—U.S.N.M. No. 167179, same data as holotype except date, August 11, 1951, 166 mm.; U.S.N.M. No. 115152, Hull Island, reef, July 13, 1939, Leonard P. Schultz, 157 mm.; Stanford Mus. No. 12280, Cocos Island, Costa Rica, Hopkins-Stanford Galapagos Expedition, 1898-1899. (Precise proportional measurements and scale and gill raker counts were not made on the Cocos Island specimen).

Diagnosis.—No black spot at axil of dorsal or anal fin; teeth of upper jaw with 4 denticulations, of lower jaw 3, on lateral edge of expanded tips; membranes of pectoral fin dark brown; caudal concavity 5.8 to 6.2 in standard length; dorsal soft rays 27 or 28.

Description.—Dorsal rays VIII, 27 (27 to 28); anal rays III, 25; pectoral rays 17 (16 to 17); anterior gill rakers 28 (26 to 29); posterior gill rakers 35 (34 to 37); scales from gill opening to posterior end of caudal peduncle spine 95 (94-104); upper teeth 44, lower teeth 60.

Depth of body 1.85 (1.94 to 1.95), length of head 3.48 (3.27 to 3.61), length of snout 4.34 (4.36 to 4.74), length of pectoral fin 3.10 (3.02 to 3.13), length of pelvic fin 2.94 (2.91), length of 8th dorsal spine 5.09 (5.24 to 5.27), length of longest dorsal ray 5.14 (4.62 to 4.89), length of third anal spine 5.89 (5.81 to 6.15), length of longest anal ray 5.01 (5.42 to 5.44), caudal concavity 6.20 (5.81 to 5.93), all in standard length. Greatest diameter of eye 4.41 (4.26 to 4.40), width of inter-orbital space 3.06 (2.87 to 3.1), least depth of caudal peduncle 2.27 (2.19 to 2.34), length of caudal peduncle spine 2.90 (2.42 to 2.67), distance from base of upper lip to distal ends of upper teeth 5.1 (4.9 to 5.1), all in length of head.

Inner surfaces of lips and margin of upper lip smooth; margin of lower lip, especially posteriorly, papillate. Upper teeth with 4 (rarely 3) denticulations (the one at the tip being longest); lower teeth with 3 denticulations (counting tip).

Color in alcohol dark brown with numerous small pale spots on the body and pectoral fin (these spots are faint and difficult to see even in freshly preserved fish); all fins brown; dorsal and anal fins with about 9 or 10 longitudinal dark brown lines (fewer anteriorly in these fins).

Color in life dark brown with head, body, and pectoral fins profusely covered with small bright blue spots, hence the name, *cyanoguttatus.*

Remarks.—This species was observed by me in its natural habitat on two occasions at Onotoa, Gilbert Islands. It was seen in small rapidly-moving schools in moderately rough water in broad shallow surge channels on the lee side of the atoll. It was a mode of life similar to that of *Acanthurus guttatus,* the latter species schooling in the rougher water of sharply-defined surge channels on the windward side of the atoll. The spotting of the body of both these species might be associated with the masses of small swirling air bubbles in the water that characterize the surf zone where they live.

Taxonomic Discussion.—*Acanthurus guttatus* Kittlitz was a brown fish with blue spots and 8 dorsal spines. Cuvier & Valenciennes, realizing that this could not be the *A. guttatus* of Bloch & Schneider, gave the species the name *marginatus.* It is possible that this species was *Ctenochaetus cyanoguttatus.* But no mention was made of the important item of dentition, although the teeth in Kittlitz' figure are drawn fairly long. The count of dorsal spines cannot be considered too diagnostic, for species of *Acanthurus* have been recorded with 8 instead of 9 dorsal spines because of the inconspicuous nature of the first spine. Even the blue spots are not unique, for adult *Acanthurus nigroris* Cuvier & Valenciennes (=*Hepatus atramentatus* Jordan & Evermann) at Wake Island had the usual blue lines broken up into spots, which gave this species an appearance much like *C. cyanoguttatus.* In view of this, and the fact that the Kittlitz specimen has not been located, describing the species as new seems in order. The Kittlitz specimen is not in the Senckenberg Museum. Günther (1861) stated that the type of *Acanthurus pyroferus* described by Kittlitz from the same publication was in the old St. Petersburg Museum. The specimen of *A. marginatus* may be there; I have been unable to complete correspondence on the matter.

The Cocos Island specimen of Snodgrass & Heller (1904) is referable to this species, although there is no record of the color in life and the spots which were probably present have now faded. G. S. Myers, who kindly loaned the specimen (SU 12280) to me, states that only one other of the four specimens collected from Cocos is now located at the Natural History Museum, Stanford University.

CTENOCHAETUS HAWAIIENSIS, sp. nov.

Plate II, Fig. 2; Text-fig. 1 D

Ctenochaetus hawaiiensis Brock, Journ. Wildlife Man., **18**: 307. 1954 (nomen nudum; name used by Brock from a personal communication before species published).

Holotype.—U.S.N.M. No. 167180, entrance to Keauhou Bay, Hawaii, Hawaiian Islands, depth of water about 12 feet, February 8, 1952, spear, John E. Randall, 197.5 mm. in standard length.

Paratypes.—U.S.N.M. No. 167181, Keahole Point, Hawaii, Hawaiian Islands, depth of water 40 feet, June 18, 1953, spear, Vernon E. Brock, 2 specimens, 204 and 209 mm.; Standford Mus. No. 47661, same data as other paratypes, 202.5 mm.

Diagnosis.—No black spot at axil of dorsal or anal fin; teeth of upper and lower jaws with 3 denticulations on lateral edge of expanded tips; membranes of pectoral fin dark brown; twice as many teeth in lower jaw as upper; caudal fin slightly emarginate to nearly truncate; dorsal soft rays 27 or 28.

Description.—Dorsal rays VIII, 28 (27 to 28); anal rays III, 25 (25 to 26); pectoral rays 16; anterior gill rakers 25 (23 to 25); posterior gill rakers 28 (25 to 27); scales from gill opening to posterior end of caudal peduncle spine 139 (115 to 131); upper teeth 26; lower teeth 56.

Depth of body 1.81 (1.82 to 1.84), length of head 3.00 (3.27 to 3.32), length of snout 3.66 (3.81 to 3.92), length of pectoral fin 3.05 (3.07 to 3.21), length of pelvic fin 3.87 (3.61 to 3.78), length of eighth dorsal spine 4.60 (4.50 to 4.80), length of longest dorsal ray 4.12 (4.18 to 4.21), length of third anal spine 6.49 (5.96 to 6.97), length of longest anal ray 4.49 (4.50 to 4.86), caudal concavity 18.8 (15.0 to 40.8), all in standard length. Greatest diameter of eye 4.86 (4.39 to 4.85), width of inter-orbital space 3.30 (2.97 to 3.14), least depth of caudal peduncle 2.30 (2.17 to 2.38), length of caudal peduncle spine 3.14 (2.87 to 3.75), distance from base of upper lip to distal ends of upper teeth 3.66 (3.15 to 3.64), all in length of head. The last-mentioned measurement, which might also be loosely termed the height of upper lip, is greater in this species than any other in the genus (this distance in other species is contained in the head length 4.5 to 6.6 times).

Margins of lips finely crenulate; distal one-fourth of inner surfaces of lips plicate, the ridges running perpendicular to the margin. Upper and lower teeth with 3 denticulations (including tips); lower teeth about twice as numerous as upper teeth.

Color in alcohol very dark brown with many narrow pale longitudinal lines faintly visible on head and body; (these lines tend to be less irregular than those on other species; the lines on the head are somewhat diagonal); all fins dark brown.

Color in life dark olive brown (appearing almost black underwater) with fine yellowish-gray lengthwise lines on the head and body.

Remarks.—This species is thus far known only from the island of Hawaii in the Hawaiian Islands, where it is common; it is named for this locality. Fishermen have told me that it is seen rarely at the island of Maui. It certainly does not seem to be present in the waters around the island of Oahu, which are well-collected.

I have observed *hawaiiensis* underwater on only four occasions, three times as a solitary fish and once as a group of three fish. Vernon E. Brock, Division of Fish and Game, Territory of Hawaii, has told me that he has observed the species in schools.

A smaller specimen (estimated 100 mm. in standard length), yellowish-brown in color, and possibly *hawaiiensis,* was sighted by me at a depth of 70 feet in Kealakekua Bay, Hawaii, but was not taken.

CTENOCHAETUS MAGNUS, sp. nov.

Text-fig. 1 E

Ctenochaetus strigosus Fowler (in part), B. P. Bishop Mus. Bull., 38: 20. 1927 (Jarvis I.).

Holotype.—U.S.N.M. No. 163614, Malden Island (4° 03′ S., 154° 59′ W.), January 27, 1951, spear, Herbert Mann and Joseph E. King, Pacific Oceanic Fishery Investigations, 225 mm. in standard length.

Paratypes.—Stanford Mus. No. 47662, same data as holotype, 219 mm.; B. P. Bishop Mus. No. 4308, Jarvis Island (0° 23′ S., 160° 02′ W.), August 15, 1924, Whippoorwill Expedition, 205.5 mm., U.S.N.M. No. 163659, Cocos Island, Costa Rica, December 28, 1952, Bruce W. Halstead and Norman C. Bunker, 209 mm.

Diagnois.—No black spot at axil of dorsal or anal fin; teeth of upper and lower jaws with 3 denticulations on lateral edge of expanded tips; membranes of pectoral fin dark brown; 1.2 times as many teeth in lower jaw as upper jaw; caudal concavity 6 to 7 in standard length; dorsal soft rays 26 or 27.

Description.—Dorsal rays VIII, 27 (26 to 28); anal rays III, 25 (24 to 25); pectoral rays 17 (16 to 17); anterior gill rakers 28 (28 to 29); posterior gill rakers 36 (35 to 36); scales from gill opening to posterior end of caudal peduncle spine 159 (149 to 164); upper teeth 59; lower teeth 68.

Depth of body 2.14 (2.02 to 2.13), length of head 3.14 (3.32 to 3.48), length of snout 4.60 (4.18 to 4.76), length of pectoral fin 3.13 (3.05 to 3.17); length of pelvic fin 2.87 (2.98 to 3.16), length of eighth dorsal spine 5.00 (5.76 to 5.97), length of longest dorsal ray 5.92 (5.54 to 5.63), length of third anal spine 6.52 (6.26 to

6.74), length of longest anal ray 6.00 (5.02 to 6.44), caudal concavity 5.63 (6.04 to 7.45), all in standard length. Greatest diameter of eye 5.07 (4.50 to 4.88), width of inter-orbital space 2.87 (3.00 to 3.07), least depth of caudal peduncle 2.27 (2.22 to 2.47), length of caudal peduncle spine 2.36 (2.33 to 2.57), distance from base of upper lip to distal ends of upper teeth 5.28 (4.5 to 5.3), all in length of head.

Margins and inner surfaces of lips smooth. Upper and lower teeth with 3 denticulations (including tips).

In alcohol the color of this species is uniform dark brown. The only record of color in life which I have is that given by Fowler (1927) for the Jarvis Island specimen. He states that the body including the pectorals was covered all over with fine blue-gray dots.

Remarks.—Thus far *Ctenochaetus striatus* (and *C. strigosus* as well) is not known from Malden, Jarvis and Cocos Islands, in spite of its common occurrence elsewhere in the tropical Pacific. These islands are the sole known localities for *C. magnus.*

Assuming that *Ctenochaetus* is Indo-Pacific in origin, which seems reasonable in view of the distribution of the species of this genus and the Acanthuridae in general, one must explain how *magnus* (and *cyanoguttatus*) crossed the East Pacific barrier (Ekman, 1953). Malden Island and especially Jarvis Island are near the counter-equatorial current which could conceivably carry fish larvae the great distance to Cocos Island (possibly via the Galapagos Islands). Herre (1940) discusses this mode of transport.

This species is named *magnus* in reference to its large size.

CTENOCHAETUS TOMINIENSIS, sp. nov.

Text-fig. 1 F

Ctenochaetus strigosus Fowler & Bean (in part), U. S. Nat. Mus. Bull., 100, 8: 200. 1929 (Gulf of Tomini, Celebes, only).

Holotype.—U.S.N.M. No. 136112, Sadaa Island, Gulf of Tomini, Celebes, November 17, 1909, dynamite, *Albatross* Philippine Expedition, 98 mm. in standard length.

Paratypes.—U.S.N.M. No. 136093, Buka Island, Gulf of Tomini, Celebes, November 20, 1909, dynamite, *Albatross* Philippine Expedition, 4 specimens, 74 to 100 mm.; Stanford Mus. No. 47663, same data as other paratypes, 87 mm.

Diagnosis.—A black spot at axil of both the dorsal and the anal fins; teeth of upper jaw with 3 denticulations on upper lateral edge of expanded tips; teeth of lower jaw with 3 denticulations; membranes of caudal fin, posterior parts of dorsal and anal fins and pectoral fins pale; margins of lips papillate; dorsal soft rays 24 or 25.

Description.—Dorsal rays VIII, 24 (25); anal rays III, 22 (22 to 23); pectoral rays 15, 16 (15 to 16); anterior gill rakers 21 (20 to 21); posterior gill rakers 20 (20); scales from gill opening to posterior end of caudal peduncle spine 91 (83 to 86); upper teeth 33; lower teeth 32.

Depth of body 2.04 (1.80 to 2.00), length of head 3.49 (3.22 to 3.37), length of snout 4.56 (4.40 to 4.65), length of pectoral fin 3.06 (2.69 to 3.03), length of pelvic fin 3.50 (3.28 to 3.59), length of eighth dorsal spine 6.12 (5.33 to 6.06), length of longest dorsal ray 3.50 (3.57 to 4.40), length of third anal spine 6.95 (5.87 to 6.90), length of longest anal ray 3.92 (4.00 to 4.11), caudal concavity 5.03 (4.35 to 6.52), all in standard length. Greatest diameter of eye 3.37 (3.17 to 3.53), width of inter-orbital space 2.92 (2.81 to 3.09), least depth of caudal peduncle 2.29 (2.23 to 2.44), length of caudal peduncle spine 2.55 (2.50 to 3.25), distance from base of upper lip to distal ends of upper teeth 6.20 (6.00 to 6.10), all in length of head.

Margins of lips papillate or crenulate, inner surfaces smooth. Upper teeth with distal half of the expanded ends smooth and blade-like and basal half divided into 3 (rarely 2) lateral denticulations; lower teeth with 3 (occasionally 4) denticulations (including tip).

Color in alcohol brown with a jet black spot at the base of the last few dorsal and anal fin rays, these spots extending slightly on to the caudal peduncle; caudal fin pale yellowish, gradually becoming brown basally, outer portions of the soft dorsal and anal fins pale yellowish, especially posteriorly, basally brown like body; outer portion of the brown part of these fins with about 3 to 5 narrow pale horizontal bands (difficult to see on some specimens) which become confluent with the pale distal region of the fins as they pass posteriorly; pectoral fins with rays brownish, membranes pale; pelvic fins brown, a little darker terminally.

The following color note from fresh specimens was taken from Fowler & Bean (1929); it was associated with this species by means of *Albatross* field numbers. "Brownish, dark in life, spotting of side of head indistinct, lower part slightly paler. Dorsal olive, with 5 or 6 bars, beginning as darker olive and on soft fin become cadmium or orange, fuse on fin posteriorly and terminally to form entire color; extreme fin edged narrowly black above; black blotch at axil. Anal like dorsal. Caudal fades whitish. Ventral blackish terminally, membranes hyaline and scattered small, orange, basal spots, rays probably black in life."

Remarks.—Named *tominiensis* for the Gulf of Tomini, Celebes.

CTENOCHAETUS BINOTATUS, sp. nov.

Text-fig. 1 G

Ctenochaetus strigosus Fowler & Bean (in part), U. S. Nat. Mus. Bull., 100, **8**: 200. 1929 (Philippine Is. and East Indies).

Holotype.—U.S.N.M. No. 136125, Pagapas Bay, Luzon, Philippine Islands, February 20, 1909, dynamite, *Albatross* Philippine Expedition, 111 mm. in standard length.

Paratypes.—U.S.N.M. Nos. 136061, 136064, 136073, 136075 to 136080, 136083, 136095, 136099, 136102 to 136105, 136109, 136111, 136114, 136116, 136119, Philippines and Moluccas, January 20, 1908, to November 24, 1909, all taken with use of dynamite except one specimen from market at Cebu Island, *Albatross* Philippine Expedition, 27 specimens, 79 to 141 mm.; Stanford Mus. No. 27174, Jolo, Philippines, August 15, 1931, A. W. Herre, 2 specimens, 106 and 121 mm.

Diagnosis.—A black spot at axil of both the dorsal and anal fins; teeth of upper jaw with 6 denticulations, of lower jaw 3, on lateral edge of expanded tips; membranes of caudal fin and dorsal and anal fins dark brown; membranes of pectoral fin hyaline; margins of lips smooth; dorsal soft rays 24 to 27 (mostly 26).

Description.—Dorsal rays VIII, 25 (24 to 27), anal rays III, 23 (22 to 25), pectoral rays 16 (15 to 16), anterior gill rakers 29 (23 to 29), posterior gill rakers 24 (22 to 27), scales from gill opening to posterior end of caudal peduncle spine 102 (93 to 100), upper teeth 39, lower teeth 42.

Depth of body 1.93 (1.88 to 2.03), length of head 3.47 (3.29 to 3.79), length of snout 4.74 (4.77 to 5.47), length of pectoral fin 2.77 (2.86 to 3.10), length of pelvic fin 3.47 (3.44 to 3.78), length of eighth dorsal spine 5.84 (5.64 to 6.15), length of longest dorsal ray 3.77 (3.61 to 4.58), length of third anal spine 5.84 (5.81 to 6.21), length of longest anal ray 4.21 (4.20 to 4.74), caudal concavity 4.27 (4.51 to 6.15), all in standard length. Greatest diameter of eye 3.41 (3.12 to 3.91), width of inter-orbital space 2.91 (2.60 to 3.16), least depth of caudal peduncle 2.19 (1.97 to 2.32), length of caudal peduncle spine 2.74 (2.43 to 3.60), distance from base of upper lip to distal ends of upper teeth 6.4 (5.5 to 6.6), all in length of head.

Margins and inner surfaces of lips smooth. Upper teeth with expanded distal part divided into 6 approximately equal lateral denticulations; lower teeth with 3 denticulations (counting tip).

Color in alcohol brown with pale lengthwise lines on the body, (much as in *strigosus* except these lines are about twice as broad as the alternate darker brown lines); a prominent black spot at the base of the last few dorsal and anal fin rays, these spots extending narrowly on to the caudal peduncle; median fins brown; pectoral rays light brownish, the membranes hyaline; margin of uppermost principal pectoral ray dark brown; pelvic fins yellowish, lateral edges and ends of rays brownish.

There is no positive record of the color in life. Fowler & Bean (1929) give a color note for three specimens, one of which was identified as the type of *binotatus* by virtue of the *Albatross* field number; however, one of the remaining specimens (the other was not located) proved to be *C. striatus*. The color description is as follows: "Fine stripes of light bluish on the shoulder at and below the pectoral base and body posteriorly greenish. On dorsal 5 or 6 densely greenish stripes, similarly on anal. First pectoral ray very dark, center of fin yellow. Ventrals like body. Some examples with fine lines on body very deep violet." Both the type of *binotatus* and the one specimen of *striatus* faintly show in the preserved state the narrow lengthwise lines posteriorly on the body as well as the shoulder and pectoral region. It seems odd that the posterior markings would not be apparent in life.

Remarks.—Named *binotatus* for the two black marks, one at the axil of the soft dorsal fin and the other at the axil of the anal fin.

A recently-transformed 35 mm. specimen of *Ctenochaetus* (U.S.N.M. No. 167177), collected in the lagoon at Onotoa Atoll, Gilbert Islands, by the author was noted to have a brilliant yellow caudal peduncle and caudal fin and stood out in sharp contrast to the young of *C. striatus* picked up at the same time. Examination of the preserved specimen some months later revealed the last few rays of the soft dorsal and anal fins to be colorless and a small spot to be present in each fin at the base of these rays; small dark brown spots were observed on the head and anteriorly on the body. Meristic data are as follows: D VIII, 27; A III, 25; pectoral rays 15; anterior gill rakers 27; posterior gill rakers 27, upper teeth 22, lower teeth 22. The upper teeth bear 6 or 7 denticulations (usually 7) and the lower teeth 3 or 4 (mostly 4). Of the known species of *Ctenochaetus*, this specimen would best receive the label of *binotatus*; however, there are some obvious differences such as coloration and structure of the teeth. Since no specimens of *binotatus* below 79 mm. in standard length are available for comparison and none of any size from Gilbert Islands (if the species occurs there), the differences observed may be due to the juvenile nature of the specimen or the geographical separation of the Gilbert Islands from the Philippines and East Indies. It is certain that the specimen is not *Ctenochaetus flavicauda* Fowler, for the latter is a variant of C. *strigosus,* and probably had a white tail in life instead of a yellow one.

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[2] See synonymy for taxonomic references.

EXPLANATION OF THE PLATES

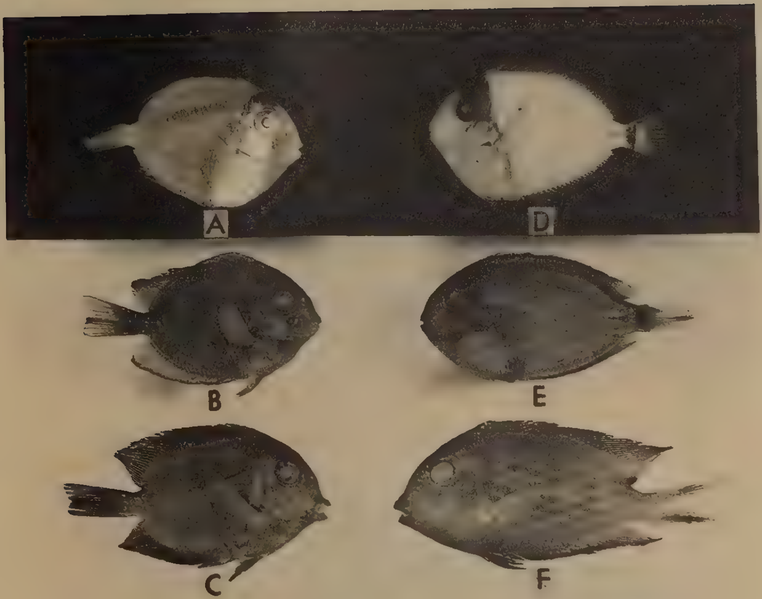
PLATE I

Acronurus, postacronurus, and juvenile stages of *Ctenochaetus*. A to C. *strigosus*. D to F. *striatus*. Natural size.

PLATE II

FIG. 1. *Ctenochaetus strigosus* (Bennett). 95 mm. specimen from the Hawaiian Islands drawn by Miss Marion Adachi.

FIG. 2. *Ctenochaetus hawaiiensis*, sp. nov. Drawing of holotype by Miss Marion Adachi.



A REVISION OF THE SURGEON FISH GENUS CTENOCHAETUS, FAMILY ACANTHURIDAE, WITH DESCRIPTIONS OF FIVE NEW SPECIES

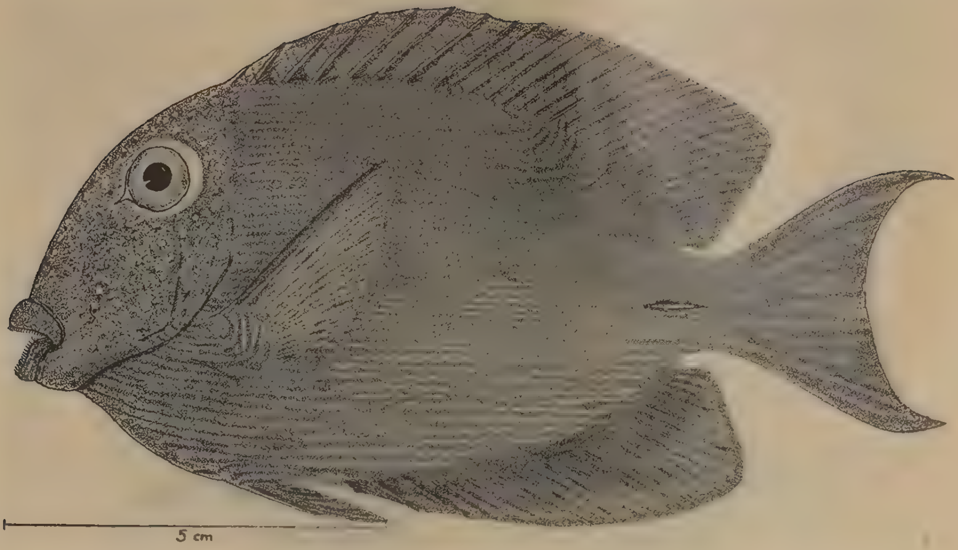


FIG. 1

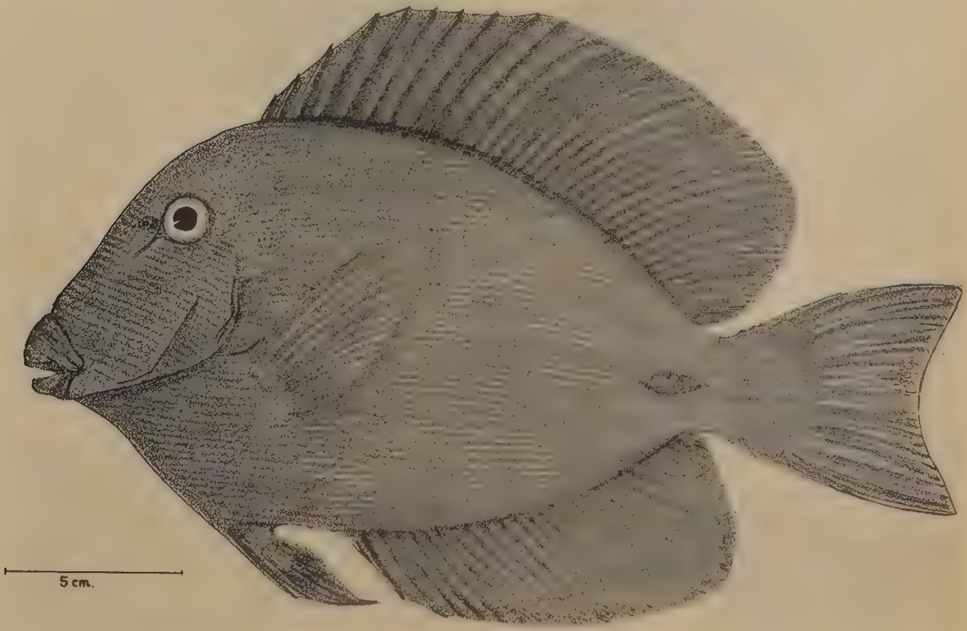


FIG. 2

A REVISION OF THE SURGEON FISH GENUS CTENOCHAETUS, FAMILY ACANTHURIDAE, WITH DESCRIPTIONS OF FIVE NEW SPECIES

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Variation in Egg and Larva Production of the Anchovy, *Stolephorus purpureus* Fowler, in Kaneohe Bay, Oahu, during 1950–1952[1]

ALBERT L. TESTER[2]

INTRODUCTION

A SMALL ANCHOVY known locally as the nehu is the principal baitfish used in Hawaii for catching skipjack (*Katsuwonus pelamis*) by live-bait fishing methods (F. C. June, 1951). This baitfish, which is taken commercially by nightlight methods after dark or by surround net in the daytime, occurs in quantity only in a few localities on Oahu, e.g., Pearl Harbor, Honolulu Harbor, Ala Wai Canal, and Kaneohe Bay, all of which are shallow, relatively turbid, and in part brackish. These bays and inlets appear to support separate populations (Tester and Hiatt, 1952). As the supply of nehu comprising the populations appears to fluctuate both seasonally and annually, it is of interest and importance to investigate the causes. One possible factor, variation in egg and larva production, is dealt with here for one population, that of Kaneohe Bay, over a period of 24 consecutive months in the years 1950, 1951, and 1952.

Pertinent information on the spawning habits of the nehu, nature of the eggs and larvae, and the larval growth rate has been given by Tester and Yamashita (1950), Tester (1951), and Yamashita (Ms.). Briefly, the nehu is a pelagic spawner, spawning takes place (in Kaneohe Bay) mostly from 10:00 P.M. to midnight, the bluntly ovoid eggs hatch within about 24 hours or less, the typically clupeid, filiform larva measures about 2 mm. at hatching and appears to have an initial growth rate of about 1.5 mm. per day. A more detailed description of eggs and larvae, including criteria for identification, is given by Tester (1951: 326–327).

Previous studies on the distribution of nehu eggs and larvae in Kaneohe Bay were conducted by Tester (1951) in 1949 and 1950. In these, four general surveys of horizontal distribution (in September, December, March, and June) were made, together with interim surveys of horizontal and vertical distribution. Among other things it was found that (a) spawning took place in all months which were sampled, and no particular spawning season could be defined from the data, (b) the eggs were present at all depths but with a slightly greater abundance towards the surface, (c) most of the eggs occurred within the southern sector of the bay (Fig. 1), (d) within the southern sector, there appeared to be a consistent peak of abundance of eggs in the vicinity of Stations 4 and 5 (between Coconut Island and Mokapu Peninsula), (e) within the southern sector, the larvae appeared to move in a clockwise direction around the bay as they increased in size. It was recommended that a specific sampling program be undertaken at or near Station 4 to investigate in more detail the temporal distribution of eggs and larvae. The recommended program, cur-

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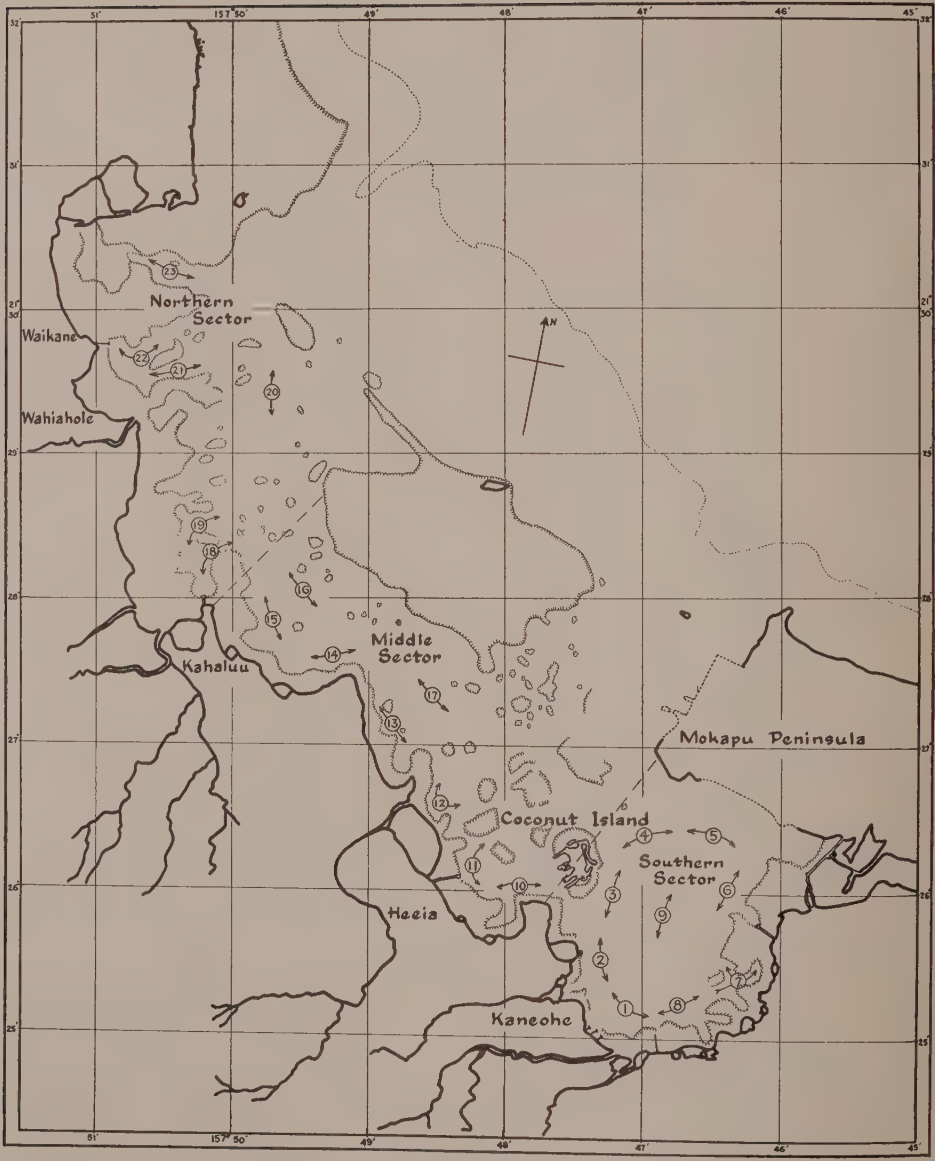
51'
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FIG. 1. Map of Kaneohe Bay showing the location of Station 4 (between Coconut Island and Mokapu Peninsula) with respect to the 23 stations sampled in a previous investigation.

tailed in some aspects and expanded in others, was started in 1950 and the data obtained form the basis for the present paper.

Acknowledgments

The investigation could not have been undertaken with efficiency without the specialized knowledge and ever-willing cooperation of Mr. Zukeran, skipper of the University's research vessel "Salpa." He assumed the responsibility of locating the sampling stations and of supervising the sampling procedure. Assistance by several graduate students of the University of Hawaii in field work and particularly in sorting plankton hauls in the laboratory, in counting nehu eggs and larvae, and in measuring fish is also gratefully acknowledged. These included Miss Tetsuko Fujita, Mr. Michio Takata, Mr. Royden Ikeda, and Mr. Austin Pritchard.

METHODS AND MATERIAL

Eggs and larvae were collected with specially constructed plankton nets having a mouth opening of 50 cm. and an overall length of 2 meters. They were modeled after the Hensen egg net, i.e., the diameter expanded to 75 cm. over a distance of 30 cm. back of the mouth, and then contracted in a cone with a 9 cm. diameter at the cod end. The forward expanding part was made of light canvas; the after conical part was made of No. 40 mesh, xxx grit gauze (aperture 0.47 mm.). An Atlas current meter was suspended in the center of the mouth by three wire supports equipped with turnbuckles. A cod end, also of No. 40 mesh grit gauze, 30 cm. in length and 9 cm. in diameter, was fastened to the end of the net by a detachable net band.

Sampling was confined to the vicinity of Station 4, located between Coconut Island and Mokapu Peninsula (Fig. 2) where as already indicated, previous work had shown a fairly consistent peak of abundance of nehu eggs (Tester, 1951: 336). Three substations (A, B, and C) were chosen at the apices of an equilateral triangle such that they were approximately 800 meters apart. Their positions were fixed by reference points on shore so that they could be located with reasonable precision on each trip.

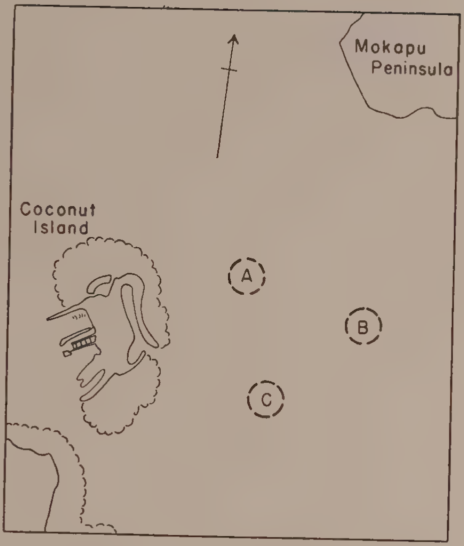

FIG. 2. Map showing the location of Substations A, B, and C at Station 4.

Hauls were made twice a week, usually on Tuesday and Friday or on Monday and Thursday, starting August 31, 1950 and ending September 2, 1952. The sequence was interrupted only in two weeks when the "Salpa" was out of commission, and only one haul per week was made. On two occasions when the "Salpa" was in drydock, the hauls were made from a 24-foot plane personnel boat, but the methods and procedures were essentially similar to those used with the other vessel.

On each trip to Station 4, one 5-minute haul was made at each of the three substations, following a circular course with a diameter of about 300 meters. The circular rather than straight line course was chosen in order to keep the sampling within the presumed area of egg concentration and to avoid a bias associated with direction and distance of haul (Tester, 1951: 332).

Each haul was made in precisely the same manner. The current meter was read; the net was lowered over the side; the ship's speed was increased from 0 to about 2 to 3 knots so that the upper edge of the mouth of the net was towed about 15 cm. below the surface of the water at a distance of about 25 meters astern. During the first haul in each set of three, the temperature was read to the nearest tenth of a degree (C.) from a freshly-scooped bucket of sea water, and a sample of sea water was taken for later chlorinity determination in the laboratory. At the end of exactly five minutes, the ship was stopped, the net was hauled alongside by hand, the current meter was re-read, the net was thoroughly washed from the outside with a power hose, it was hauled aboard, the cod end was removed and the contents placed in a quart jar with the usual care in rinsing, washing, etc. The jar was then labelled and formalin was added to make a solution of approximately 10 per cent.

In the laboratory, the plankton was placed in Petri dishes, sorted by eye and by low power dissecting microscope, and all nehu eggs and larvae were removed and counted. The larvae were subsequently checked for correct indentification under higher magnification and were measured to the nearest 0.1 mm. from the tip of the closed lower jaw to the base of the tail, using an ocular micrometer. Chlorinity of the water samples (p.p.-m.) was determined by the Mohr method.

The Atlas current meters were standardized by determining the number of revolutions made in towing them at slow speed (about 3 knots—equivalent to about 3.7 revolutions per second) back and forth over a known distance between two buoys. There was close agreement between the calibration of the two meters, one of which was used for about 18 months and the other for the remaining 6 months. Calibration was undertaken but once rather than at intervals during the period of use. It is believed that this negligence led to no great error as (a) the meters were kept oiled, (b) the jewel bearings remained intact, and (c) there was no indication of a progressive change in the number of revolutions per 5-minute haul over the period of use.

As the hauls were standardized in time, the variation in volume of water strained from haul to haul was relatively small. Adjustment of the egg counts to a standard volume of water (100 cubic meters—a rough average of the actual volume strained per haul) was made, although it did not greatly alter the counts nor influence the major conclusions drawn from unadjusted data. The adjustments were made according to the following formula which is similar to that of Ahlstrom (1953: 6):

$$E_s = \frac{100\ E}{R.a.p.} = \frac{1{,}369.072\ E}{R}$$

where E_s is the number of eggs adjusted to a volume of 100 cubic meters of surface water;

E is the number of eggs per haul;

R is the number of revolutions of the meter per haul;

a is the area of cross-section of the mouth of the net (0.19635 square meters);

p is the length of the column of water needed to effect one revolution of the meter (0.372 meters).

The adjustment was not made for the larva count as the numbers involved were small and in most cases remained unchanged when the adjusted values were rounded to the nearest whole number. The unadjusted data may be considered to represent the number of larvae per 100 cubic meters of surface water.

RESULTS

Variation with Substation

Adjusted egg counts at Substations A, B, and C ranged respectively from 0 to 1,661, 0 to 1,722, and 0 to 2,617, with grand arithmetic means of 60.6, 61.8, and 81.1 eggs per 100 cubic meters for the 207 sampling days

TABLE 1

ANALYSIS OF VARIANCE OF (TRANSFORMED) EGG AND LARVA COUNT OVER A TWO YEAR PERIOD

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
Egg Count:				
Substations	2	0.6248	0.3124*	3.2
Days	206	416.5646	2.0222**	21.0
Error	412	39.6087	0.0961	—
Larva Count:				
Substations	2	0.0184	0.0092	0.2
Days	206	65.9477	0.3201**	6.4
Error	412	20.5733	0.0499	—

* P about 0.05; ** P less than 0.01.

over the 2 year period. In the basic adjusted data, the range (and hence the standard deviation) of the substation determinations was obviously correlated with the mean, indicating the need for a transformation of the data in order to apply tests of significance. A logarithmic transformation was used: $y = \log (x + 1)$ (Barnes, 1952: 65); this not only tended to decorrelate the standard deviation and the mean but also avoided the logarithm of zero.

The transformed data were analyzed according to two criteria of classification, substations and days, with the results included in Table 1. There are highly significant differences between the three geometric means for substations: A–6.36, B–7.94, and C–8.80. Apparently on the average, Substation C was located closest to the focus of abundance of eggs in the southern sector of the bay (Tester, 1951: 336). The large and highly significant variation between sampling days was anticipated, and reflects both erratic daily egg production and seasonal variation in spawning activity.

Larva counts at Substations A, B, and C ranged respectively from 0 to 62, 0 to 51, and 0 to 57, with grand arithmetic means of 2.66, 2.18, and 2.44 larvae per 100 cubic meters. As shown in Table 1, there were no significant differences between the geometric means for substations (A–0.97, B–0.92, and C–0.98) but, as in the case of the eggs, there were highly significant differences between the means for days.

The great decline in numbers between the egg and larva stage is worthy of note and will be referred to again. For the grand arithmetic mean the decline is from 67.8 to 2.4 (96.5 per cent) and for the grand geometric mean it is from 7.01 to 0.96 (86.3 per cent.)

Variation with Time

The logarithms of the adjusted egg counts were averaged for each sampling day and were plotted against time (the detailed graph is not reproduced). It was at once apparent that there was considerable variation in mean egg count between successive sampling days during certain months. For example, on June 5, 8, and 12, 1951, the geometric mean counts per 100 cubic meters were respectively 10.2, 607.0, and 21.2; on July 2, 5, and 9, 1951, they were 0.8, 537.4, and 288.0. It is possible that this large daily variation in egg count could be due to shifting of the focus of spawning to and away from the vicinity of Station 4. However, it seems more likely that it is due mostly to large daily variation in actual egg production and thus in spawning activity. If so, it would be of interest to discover the cause or causes.

Perusal of the data on temperature and salinity indicated that these factors per se were not responsible for the variation in egg count between sampling days. It was apparent, without statistical analysis, that there was no significant relationship.

Attention was next directed to the possibility of lunar effects. On the basis of one series of samples taken in Ala Wai Canal during July, 1949, Tester and Yamashita (1950: 1) suggested that spawning activity might be related to the lunar cycle, with maximum spawning during the first quarter and minimum spawning during new moon. To investigate a possible lunar relationship, geometric means of the adjusted egg counts were calculated according to lunar days for the years 1950–51 and 1951–52. The data were then grouped according to phases of the moon. The geometric means for dark, first quarter, full, and third quarter were respectively 13.63, 18.20, 13.55, and 12.04 in 1950–51, and 4.53, 3.54, 2.61, and 2.66 in 1951–52. The differences in mean count between phases were neither statistically significant nor were they consistent during the two years. The present data yield no evidence of lunar periodicity in spawning. The cause or causes of the large variation between successive sampling days remains unknown.

Despite the large variation between successive sampling days it is evident from the data that spawning is seasonal in nature with a peak production of eggs during the summer months and a low production during the winter months. This is best illustrated by the geometric means per 100 cubic meters according to successive months as given in Table 2 and portrayed on a logarithmic ordinate scale in Figure 3A. Average production of eggs was highest during July, 1951, and next highest during August, 1952. It was relatively low during the winter months of 1950–51, and still lower during the winter months of 1951–52.

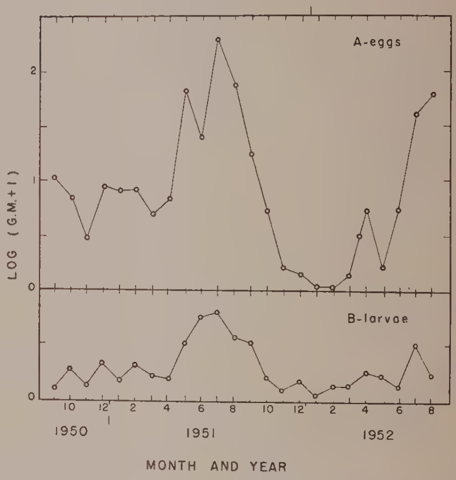

FIG. 3. Seasonal variation in the abundance (logarithm of the geometric mean plus one) of (A) eggs and (B) larvae.

The seasonal march of egg production follows closely the seasonal march of temperature (Table 2), but this does not necessarily imply a dependent relationship. There is a marked difference in egg production between 1950–51 and 1951–52 (September to August, inclusive) with a geometric mean for the former of 14.12 and for the latter 3.27 eggs per 100 cubic meters. For the corresponding periods, mean water temperatures were 25.00° C. and 24.38° C. and mean chlorinities were 18.91 p.p.m. and 19.10 p.p.m., suggesting that higher temperatures and/or lower chlorinities were favorable for greater egg production. This possibility was investigated further using as variates the difference (with due regard to sign) between the means for the same months in the two years for temperature, chlorinity, and log egg count. Neither of the two partial regression coefficients (0.22 for log egg count and temperature; 0.06 for log egg count and chlorinity) was significant. The multiple correlation coefficient ($R = 0.41$) indicated that 83 per cent ($1-R^2$) of the total variation in egg count differences was unexplained by variation in the differences for temperature and chlorinity. It may be pointed out that this method of handling the data nullifies the seasonal trends. Although the results suggest that temperature may influence

TABLE 2
GEOMETRIC MEAN (G.M.) EGG AND LARVA COUNTS AND ARITHMETIC MEAN TEMPERATURES (°C.) AND CHLORINITIES (P.P.M.) ON A MONTHLY BASIS

MONTH AND YEAR	EGGS		LARVAE		TEMPERATURE	CHLORINITY
	Log (G.M. + 1)	G.M.	Log (G.M. + 1)	G.M.		
9/50	1.0223	9.53	0.1129	0.30	26.7	19.41
10/50	0.8504	6.09	0.2924	0.96	26.4	19.50
11/50	0.4855	2.06	0.1534	0.42	25.0	19.06
12/50	0.9485	7.88	0.3331	1.15	22.4	18.25
1/51	0.9234	7.38	0.1996	0.58	22.8	19.07
2/51	0.9289	7.49	0.3280	1.13	22.9	18.98
3/51	0.7028	4.04	0.2305	0.70	23.1	17.85
4/51	0.8264	5.70	0.1988	0.58	24.4	18.49
5/51	1.8148	64.30	0.5071	2.22	25.8	18.87
6/51	1.4007	24.20	0.7074	4.10	26.8	19.04
7/51	2.3013	199.10	0.7487	4.61	26.7	19.18
8/51	1.8714	73.40	0.5842	2.85	27.0	19.24
9/51	1.2416	16.40	0.5409	2.47	27.4	19.27
10/51	0.7202	4.25	0.2013	0.59	26.3	19.11
11/51	0.2159	0.64	0.0957	0.25	24.6	19.09
12/51	0.1403	0.38	0.1746	0.50	23.2	18.65
1/52	0.0334	0.08	0.0576	0.14	22.2	18.73
2/52	0.0251	0.06	0.1401	0.38	22.9	18.92
3/52	0.1453	0.40	0.1357	0.37	22.4	19.26
4/52	0.7286	4.35	0.2497	0.78	23.4	19.30
5/52	0.2177	0.65	0.2182	0.65	23.9	18.98
6/52	0.7278	4.34	0.1310	0.35	24.6	19.25
7/52	1.6201	40.70	0.5042	2.19	25.5	19.29
8/52	1.7984	61.87	0.2257	0.68	26.2	19.29

egg production, this cannot be established as a conclusion from the present data.

Figure 2B shows that the larva count also varies seasonally with a high production in the summer and a low production in the winter months. As might be expected, there is high correlation between the log mean monthly egg and larva counts ($r = 0.818$; $P < 0.01$).

Mortality

When the eggs were counted, they were segregated into three categories—"normal," "damaged," and "agglutinated"—according to criteria established by Tester (1951: 325–326). The damaged eggs, with the inner membrane ruptured and the embryo shattered, were assumed to have suffered mechanical injury during capture. It was suggested that the agglutinated eggs, in which the yolk and embryo had disintegrated into a whitish mass, may have been dead before capture.

The numbers and percentages of eggs in the three categories, segregated according to months, are shown in Table 3. From the gross data, the (weighted) percentages of normal, damaged, and agglutinated eggs are respectively 46.2, 32.2, and 21.6. These may be compared with similar data collected in 1949 and 1950—48.4, 47.1, and 4.5—recalculated

TABLE 3

Number (in Parentheses) and Percentage of Normal, Damaged, and Agglutinated Eggs by Months

MONTH AND YEAR	NORMAL	DAMAGED	AGGLUTINATED
9/50	(129) 43.4	(49) 16.5	(119) 40.1
10/50	(102) 43.6	(66) 28.2	(66) 28.2
11/50	(32) 30.2	(29) 27.4	(45) 42.4
12/50	(71) 14.1	(138) 27.4	(295) 58.5
1/51	(29) 6.1	(242) 51.1	(203) 42.8
2/51	(66) 13.7	(222) 46.3	(192) 40.0
3/51	(4) 2.8	(109) 76.2	(30) 21.0
4/51	(124) 43.2	(143) 49.8	(20) 7.0
5/51	(784) 23.9	(1,386) 42.3	(1,110) 33.8
6/51	(1,830) 41.6	(1,555) 35.3	(1,018) 23.1
7/51	(6,110) 47.7	(4,648) 36.3	(2,048) 16.0
8/51	(3,991) 64.9	(1,089) 17.7	(1,072) 17.4
9/51	(528) 43.1	(323) 26.4	(373) 30.5
10/51	(292) 77.4	(32) 8.5	(53) 14.1
11/51	(19) 61.2	(7) 22.7	(5) 16.1
12/51	(5) 33.3	(4) 26.7	(6) 40.0
1/52	(2) 66.7	(0) 0.0	(1) 33.3
2/52	(0) 0.0	(0) 0.0	(2) 100.0
3/52	(1) 5.6	(6) 27.7	(12) 66.7
4/52	(47) 24.5	(143) 74.5	(2) 1.0
5/52	(3) 6.2	(23) 48.0	(22) 45.8
6/52	(23) 12.0	(81) 42.2	(88) 45.8
7/52	(521) 37.3	(450) 32.3	(424) 30.4
8/52	(1,344) 64.7	(446) 21.5	(286) 13.8
All	(16,057) 46.2	(11,191) 32.2	(7,492) 21.6

from data discussed by Tester (1951: 338–340). The differences between investigations in the last two categories may be due, in part at least, to a change in interpretation of borderline cases of the "damaged" and "agglutinated" condition, although an effort was made to acquaint each of the several plankton sorters with the same objective criteria. The indications are that the number of agglutinated eggs averaged higher in 1950–53 than in 1949–50, but perhaps in a smaller ratio than that shown by the data (21.6 to 4.5, or 5 to 1). In any case, it is believed that the interpretation of the differences between "damaged" and "agglutinated" was reasonably consistent within the recent investigation.

The monthly percentages listed in Table 3 vary widely, but show a tendency for normal eggs to be relatively more abundant than agglutinated eggs during the summer and for agglutinated eggs to be relatively more abundant than normal eggs during the winter. The seasonal trend is illustrated in Figure 4. Because of the varying inherent accuracies of the percentages it is difficult to establish the statistical significance of the seasonal change. However, it may be shown readily that the differences in monthly ratios of normal to total and of agglutinated to total are unlikely due to chance. For example, a test of independence applied to the ratios of agglutinated to total yielded an extremely high Chi-square (3,067 for 21 degrees of freedom) which was highly significant ($P < 0.001$).

If the eggs classed as agglutinated were actually dead at the time of sampling, it would seem that this source of natural mortality was more pronounced in the winter, the period of small spawning, than in the summer, the period of large spawning. This suggests a further investigation of (1) the assumption that agglutinated eggs were dead at the time of sampling, and if this is established, (2) the causes of mortality of the eggs.

Reference may again be made to the grand geometric means for eggs and larvae (7.01 and 0.96 per 100 cubic meters) and to the great reduction in numbers (86.3 per cent). As the eggs hatch within 24 hours whereas the larvae persist in the catches for several days, the mean count for eggs would be expected to be smaller rather than larger than that of the larvae. There are several possible explanations for the relatively small mean larva counts:

(a) The larvae may be carried away from Station 4 by a slow clockwise current drift as suggested by Tester (1951: 342) following a study of variation in length distribution of the larvae.

(b) The thin filiform larvae, particularly after yolk sac absorption, may slip through the meshes of the net.

(c) The newly hatched larvae may sink below the surface layer which was sampled. Yamashita (MS: 14) has shown that in aquaria the newly hatched nehu larvae tend to sink. Although in simultaneous tows made by Tester (1951: 335) there was no significant evidence of more larvae at a depth than at the surface, the numbers caught were too few to warrant a conclusion.

(d) The newly or recently hatched larvae may suffer a high natural mortality. It seems idle to speculate further on this or other possibilities in view of the probable action of (a), (b), and perhaps (c), as outlined above.

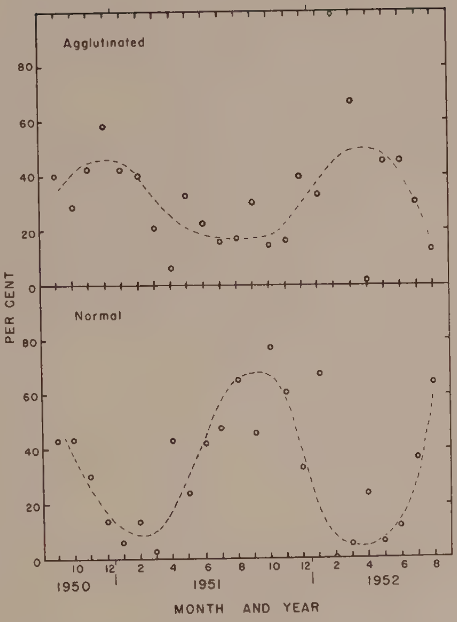

FIG. 4. Seasonal variation in the percentage of agglutinated and normal eggs.

Perusal of Table 2 will disclose that the ratio of egg to larva number varies considerably from month to month. The most striking discrepance occurs in the months of December, January, and February, 1951–52, when the mean egg count is less, rather than greater, than the mean larva count. Although in these months the comparisons are intrinsically less reliable than in others because of the small numbers involved, nevertheless the discrepance seems due to factors other than chance. The reversal of the egg to larva ratio in the winter is contrary to what would be expected from the tendency, just discussed, for the percentage of agglutinated and presumably dead eggs to be higher in the winter than the summer: this should increase rather than decrease the winter egg to larva ratio. One possible explanation of the reversal is that in the winter of 1951–52 spawning of relatively small extent took place elsewhere than at Station 4, and that the larvae drifted into the sampling area.

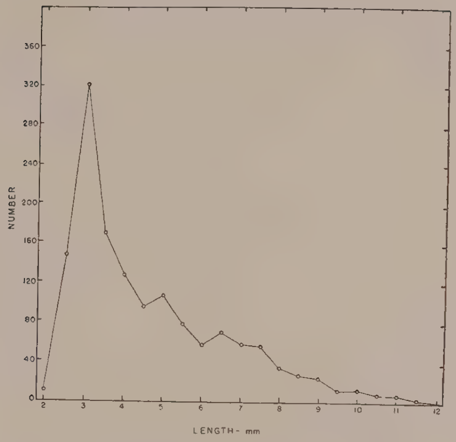

FIG. 5. Length frequency distribution of larvae.

Length Distribution of the Larvae

The nehu larvae ranged in length from about 2 to 11 mm. It is presumed that larger larvae were able to escape the net. It was hoped that the progeny of pulses of spawning could be followed by the progression of modes in the length distribution of successive samples of larvae. This was not possible because (a) the larvae were apparently dispersed from the sampling station too rapidly and (b) the samples were not taken at sufficiently close time intervals.

The composite length distribution of all larvae sampled at Station 4 is shown in Figure 5. It is similar to that shown by Tester (1951: fig. 6) in that a main mode appears at 3 mm. and less pronounced modes appear at greater lengths. The latter differ slightly in position from those reported earlier but this may be attributed to the fact that sampling was confined to one station in the present investigation and therefore did not adequately sample the larger larvae which drifted elsewhere. The minor modes are presumed to be real and to be related to the presence of "day groups." As in the previous investigation (Tester, 1951: 341), they suggest an average early growth rate of about 1.5 mm. per day.

SUMMARY AND CONCLUSIONS

1. Quantitative samples of nehu eggs and larvae were taken in replicate twice a week over a two year period at one station in Kaneohe Bay, using a half-meter plankton net. The station was located at or near a focus of abundance of eggs in the southern sector of the bay.

2. Spawning, as indicated by egg and larva catch, occurred erratically throughout the year, but with a summer maximum and a winter minimum.

3. Variation in egg production between days could not be adequately explained by variation in temperature, chlorinity, or moon phase.

4. Agglutinated eggs, with the embryo and yolk coagulated beyond recognition, formed a higher percentage than in a previous investigation. Moreover in the present material, the percentage was higher in winter than in summer. The suggestion that agglutinated eggs were dead at the time of capture should be investigated further.

5. Several possible explanations are advanced for a large decrease in numbers between the egg and larva stage, namely, drift of larvae from the sampling station, escape through the meshes of the net, sinking below the surface layers, and loss from mortality. A seasonally erratic egg to larva ratio is pointed out.

6. The sampling is not adequate to trace pulses of spawning from the egg to the larva stages. A length frequency distribution of the larvae is included showing the presence of one major and several minor modes similar to those found in a previous investigation.

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OXYGEN REQUIREMENTS OF SOME HAWAIIAN TUNA BAITFISH

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FISH AND WILDLIFE SERVICE

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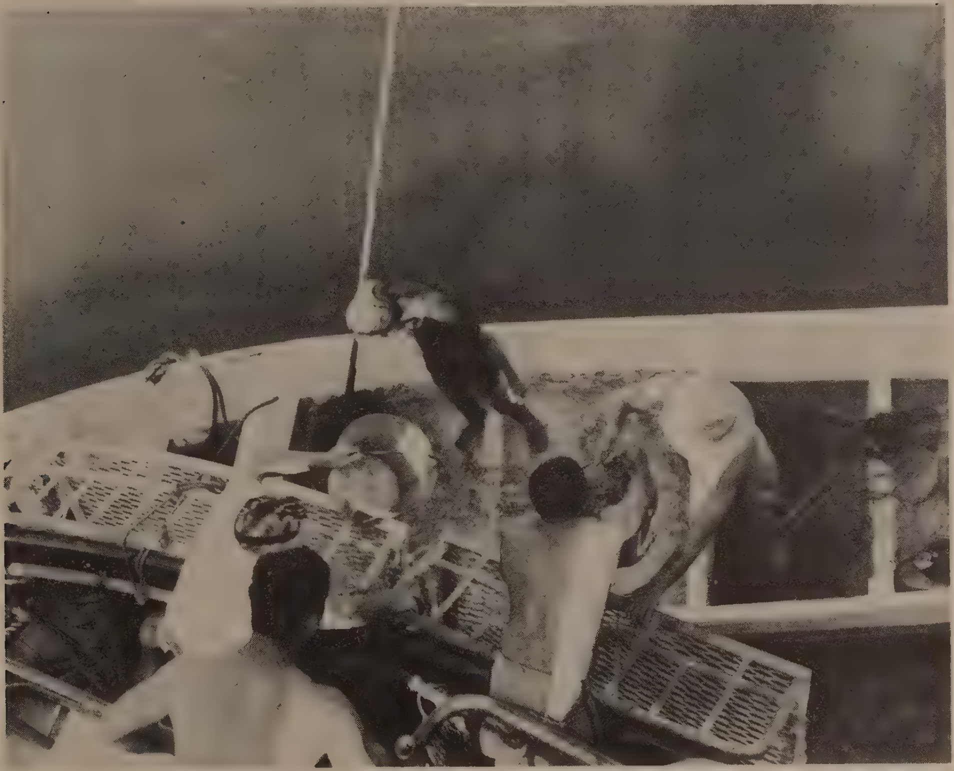

OXYGEN REQUIREMENTS OF SOME HAWAIIAN TUNA BAITFISH

By

Austin Pritchard

Contribution No. 61 from the Hawaii Marine Laboratory

Special Scientific Report: Fisheries No. 146

WASHINGTON: MAY 1955

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The success of livebait fisheries for tuna depends to a large extent on the availability of baitfish. In the Hawaiian fishery for aku (skipjack or striped tuna), Katsuwonus pelamis (Linnaeus), the two species of baitfish most commonly used are the nehu, Stolephorus purpureus Fowler, and the iạo, Pranesus insularum (Jordan and Evermann). The nehu, although the less hardy of the two, is the preferred bait. Nehu are generally caught at night by attraction to a light, and both nehu and iao are caught during the day by means of surround nets. Bait is quickly transferred from the nets to livebait wells in the fishing vessels.[1] The period following the transfer of bait is crucial in livebait fishing, for if water circulation in the live-wells is inadequate and the fish crowd together at the surface or in a corner of the well, considerable mortality may occur. The usual mortality is about 20-30 percent, most of it during the first day, but in some instances it may amount to 50-100 percent.

Heavy bait mortality is probably due to the interaction of several factors. Loss of scales and collisions with the sides of the tank probably lead, directly or indirectly, to the death of many fish. On the other hand, when fish are confined to a limited space, as they are in the livebait wells, the possible depletion of oxygen to levels causing abnormal respiration and suffocation must be considered. This problem of oxygen depletion would be especially acute in those boats (making up the majority of the fleet at present) which employ the method of circulating water through holes in the bottom the well. A few boats possess pumps for circulating water through the live-wells, and may perhaps be less concerned with the problem of oxygen depletion per se. Other questions arise, however, particularly in regard to the effect of different flow rates and various degrees of crowding upon the behavior of the fish. The local annual range of temperature is small, but the possibility of a small but sudden rise or fall in temperature, with its concomitant effects on respiratory metabolism, must be considered.

The object of the present study was to analyze, in the laboratory, the oxygen requirements of the local tuna baitfish in the hope of obtaining basic information which might be of value to livebait fisheries. An investigation of oxygen consumption under various conditions was carried out, emphasis being placed on the effects of temperature, flow rates, various degrees of crowding, and the oxygen concentration of the water. In addition, experiments were designed to determine lethal levels of oxygen for the fish.

The author takes this opportunity to thank Dr. P. B. van Weel for his guidance and constant encouragement throughout this work. Grateful acknowledgement is made to the staff of the Pacific Oceanic Fishery Investigations for advice and technical assistance. Special appreciation is also due Lester Zukeran and Charles Nakamoto of the Hawaii Marine Laboratory for taking a large share of the responsibility for catching and maintaining the stocks.

REVIEW OF THE LITERATURE

An enormous literature exists on respiratory exchange in fish and an extensive review will not be attempted here. A summary of literature relevant to this study will be presented now with mention of individual publications in connection with the appropriate sections of the work. Suehiro's (1951) study of the lethal limits of oxygen for Japanese sardines and anchovies is the only set of observations known to the author on the respiratory metabolism of baitfishes. Besides measuring lethal values of oxygen, Suehiro made several observations on the amount of oxygen consumed by baitfish in live-wells, and emphasized the superior bait-holding capacity of those bait tanks in which water was circulated by pumps.

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[1] A good description of the Hawaiian livebait fishery is given by Fred C. June (1951, Commercial Fisheries Review 13(2):1-18).

Note: Financial support for this study came from a U. S. Fish and Wildlife Service fellowship. The material reported forms the greater part of a thesis submitted to the graduate school of the University of Hawaii in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The author at present is a faculty member of the Department of Zoology, Oregon State College, Corvallis, Oregon.

The important factors of temperature and oxygen concentration have received considerable attention from investigators of fish metabolism. At present, the general nature of the effect of temperature and the importance of temperature acclimation seem clearly established (Ege and Krogh 1914; Wells 1935b, c; Sumner and Lanham 1942; Haugaard and Irving 1943), but observed differences among species make it imperative to analyze the influence of temperature on metabolic rate for each species of fish investigated. As regards the effect of oxygen concentration, it would appear that most fish are able to maintain a fairly constant level of metabolism over a wide range in oxygen concentrations (Gaarder 1918; Hall 1929; Keys 1930a, b; Lindroth 1940). There is, however, considerable variation among species as regards the critical concentration, the point at which the rate of oxygen consumption begins to decline. The role of breathing regulation in helping to maintain a constant metabolic rate as the oxygen content falls below normal has been pointed out by several workers (Westerlund 1906; Winterstein 1908; Belding 1929; Meyer 1935; van Dam 1938), but breathing movements and rate of oxygen consumption have rarely been measured at the same time.

The effect of aggregation size on metabolic rate in fish has received comparatively little attention since the initial discovery by Schuett (1933) of a "group effect" in goldfish. Essentially, he found that groups of four fish consumed less oxygen per unit weight than single fish in the same size container. His results received confirmation from Shlaifer (1938) and later Geyer and Mann (1939a, b) reported a "group effect" for the perch (Perca fluviatilis). Large groupings of fish have apparently not been investigated in this regard.

With the notable exception of Hall (1930), almost all the lethal values of oxygen reported in the literature pertain to freshwater fish (Chapman 1939; Moore 1942; Wells 1913; Townsend and Earnest 1940). Individual differences in resistance to low oxygen are pronounced, as indicated by wide range in lethal oxygen values within a species (Wilding 1939). Furthermore, lethal values of oxygen have been shown to vary with temperature and possibly with the size of the fish (Graham 1949; Keys 1931; Moore 1942).

Finally, it is apparent that most of the investigations on fish metabolism in general have been concerned with freshwater species and a need exists for more work on marine forms.

CAPTURE, MAINTENANCE, AND HANDLING OF STOCKS

Practically all the experimental work was performed between 1950 and 1953 at the Hawaii Marine Laboratory, located on Coconut Island in Kaneohe Bay, Oahu. Baitfish, particularly iao, were fairly abundant around the island and could be readily seined in shallow waters. Occasionally fish were attracted to a submerged light and caught in a net lifted from below. Initially stocks were kept in large concrete cisterns some distance away and transferred as needed to aquaria at the laboratory. Later a shallow wooden box (fig. 1) was built for keeping large numbers of fish at the laboratory. Water circulation in this container was efficient and the fish could be easily captured. The fish were fed bread crumbs daily in the early afternoon.

Although both the nehu and iao are delicate fish, the nehu in particular is highly excitable and suffers hemorrhages and loss of scales from rubbing against the sides of the tank. Suehiro (1951) mentions this as one of the principal causes of death of the anchovies (Engraulis japonicus) and sardines (Sardinia melanostica) used for bait in the Japanese tuna fishery. By the end of the summer of 1950 it was obvious that the nehu was unsuitable as an experimental animal and attention henceforth was focused almost entirely on the iao.

Stock mortalities were greatest in the summer months, and large mortalities coincided with severe hot weather, with the water temperature often rising above 29° C. Summer fish, on the whole, behaved more erratically in experiments than winter fish, and seemed particularly susceptible to small increases in temperature. Several summer experiments had to be discarded at the outset because of the obviously abnormal behavior of the fish.

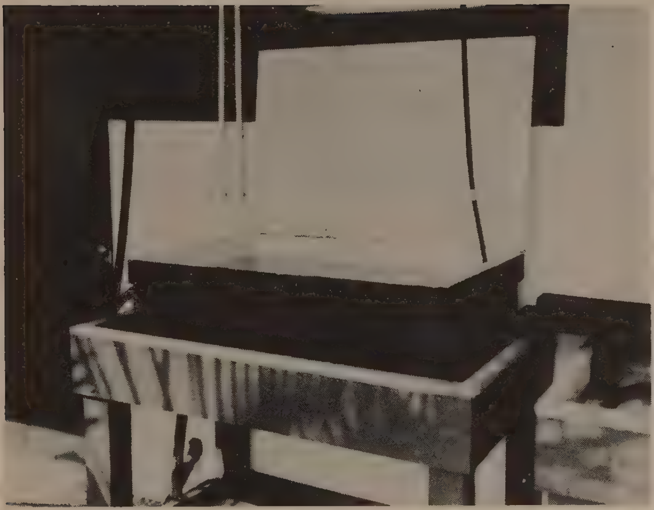

Figure 1.--Holding box for iao at the main laboratory

Two additional factors regarding stock "condition" must be considered. First, fish with injured tails, presumably chewed by other fish, were sometimes seen in the tanks. Their swimming behavior appeared to be normal. Secondly, an ectoparasite was occasionally found attached to the underbelly of the fish. To estimate the incidence of this kind of parasitism, two samples taken near the laboratory were examined. In the first sample, 1 fish out of a total of 95 showed ectoparasites; and in the second sample, only 2 fish out of 390 possessed externally visible parasites. Occasionally, one or two fish with parasites or chewed tails were discovered at the end of an experiment, but the presence of these fish did not appear to change the pattern of the results.

In view of the delicate nature of these fish, considerable care was taken in selecting and handling experimental animals. Fish dissociated from the main school and swimming weakly at the surface were removed as quickly as possible from the stock tanks. In transferring the fish, they were first lifted from the tank in a fine-meshed net, dipped into a beaker, and then poured through a plastic funnel into the experimental container.

MEASUREMENT OF DISSOLVED OXYGEN

The unmodified Winkler procedure was used to measure dissolved oxygen for all the experiments in which the water in the experimental container was continually being renewed. The method is standardized and widely used and, therefore, needs no detailed description. Essentially, the steps outlined by Tully et al. (1950) were followed both in the preparation of reagents and in the collection and preserving of samples. In those experiments where the fish were allowed to use up the dissolved oxygen in sealed jars, the permanganate modification of Winkler's method was employed to avoid possible nitrite error. The procedure followed that outlined by Welch (1948).

Several methods are available for standardizing sodium thiosulfate solutions, and their relative utility has recently been compared (Thompson and Robinson 1939). Potassium bi-iodate, as recommended by Thompson and Robinson, was used as a standard in the present study. This substance is expensive, but is relatively stable and, furthermore, consistent in its results. To standardize the thiosulfate solution, 10 ml. of 0.01 normal bi-iodate was diluted to 50 ml. with sea water, alkaline-iodide and sulfuric acid added in that order, and the released iodine titrated as usual.

METABOLIC RATE UNDER VARIOUS CONDITIONS

Although oxygen uptake is not the only index of activity of an organism, it is correlated quantitatively with rate of metabolism and heat production and is the generally accepted standard measure of metabolic processes. In the present work the terms "metabolic rate", "oxygen consumption", and "oxygen uptake" will all be taken to mean the rate of oxygen consumption, expressed as cc./gram wet weight/hour. The following problems are taken up in this section: (1) the extent of normal fluctuations in rate of oxygen consumption and the presence or absence of

24-hour cycles, (2) the influence of temperature, and (3) the effect of different flow rates, in conjunction with varying quantities of fish, on the metabolic rate. The last problem is of particular interest to the local tuna fishery, since some of the boats are installing pumps capable of regulating the flow of water through the live-wells. To my knowledge, there have been no previous investigations concerned directly with the influence of flow rate on fish metabolism, excepting a short work by Washbourn (1936), who found that the rate of oxygen consumption of trout fry in swift-flowing water was significantly higher than in stagnant water. Wells (1935a) recognized the relation and cautioned that in any series of experiments on fish respiration the flow should be maintained invariable over long periods of time.

The relationship of rate of oxygen consumption to the oxygen concentration of the water itself will be discussed in a separate section.

Apparatus and General Methods

The flowing-water method was used in measuring rate of oxygen consumption, the principal advantage being the continual removal of carbon dioxide and other metabolic products given off by the fish. Essentially, this technique consists in delivering a stream of water to the experimental jar under a constant head of pressure, oxygen samples being taken at the inlet and outlet of the jar. Knowing the weight of the fish and the rate of flow in liters/hour, the rate of oxygen consumption may be readily calculated. Keys (1930b) compared the accuracy of the flowing-water method versus the sealed-jar method and found that, with the latter, few of his determinations could be duplicated to within 15 percent. With the apparatus used in the present study, consecutive determinations (less than 15 minutes apart) never varied more than 15 percent and generally showed closer agreement (see table 4a).

The respiration assembly is pictured diagrammatically in figure 2a. The large battery-jar reservoir (B) and overflow jar (C) allowed a constant head of water to be delivered to the experimental vessel at all times, and simultaneous oxygen samples could be taken by means of the inlet siphon from the reservoir (D) and the connection for outlet samples (F). With the exception of the flow-rate experiments, a 1-gallon wide-mouth jar was used as the experimental vessel. Figure 2b shows the water bath used in the temperature experiments. Immersed in the bath were a thermostatically controlled heating unit, motor driven stirrer, and a coil of copper tubing through which cold water was pumped to lower the temperature in the bath. The entire assembly rested in a Masonite box (not shown in the figure) packed with sawdust. Figure 2c shows the storage jar (about 10 inches in diameter) employed as an experimental container in the flow-rate experiments. A piece of Masonite served as the lid, being connected by threaded brass rods to another piece at the base of the jar. Leakage was prevented by forcing the lid down on a piece of rubber tubing.

In all the experiments oxygen samples were withdrawn in a standard fashion. Sampling bottles were placed simultaneously under (D) and (F) (fig. 2a) and sufficient time was allowed for one and one-half flushings of the bottles.

At the end of an experiment, the fish were weighed to the nearest 0.1 gram on a beam balance after first blotting them on paper towels to remove excess water. Since the validity of wet weight determinations depends on the constancy of the ratio of wet to dry weight, the dry weights of several samples of iao were determined. The samples were dried overnight at 70°-80° F., placed in a dessicator, and daily weighings were taken on a triple beam balance until a constant weight was reached in each of the samples. The percentage of dry weight to wet for each of the samples is shown in table 1 and is seen to vary only slightly. The lengths of all fish used in experiments were determined to the nearest millimeter, from the tip of the snout to the end of the vertebral column.

To determine the extent of oxygen consumption or oxygen production due to plankton in the sea water line, control experiments were run, with a 22-liter carboy as the "dummy" experimental jar. Oxygen samples from inlet and outlet were taken for several hours and a statistical analysis performed on the data (table 2). Although most of the trials showed a very small decrease in oxygen content, the difference was not statistically significant.

Table 1.--Ratios of dry weight to wet weight in iao

Sample No.	Number of fish	A (wet weight)	B (dry weight)	100 B / A
		gm.	gm.	percent
1	10	10.1	2.4	23
2	12	10.6	2.5	24
3	12	11.2	2.8	25
4	16	15.7	3.9	25
5	16	11.4	2.8	24
6	25	21.1	5.3	25
7	15	18.4	4.1	22
8	15	17.2	4.4	26
9	13	16.1	3.8	24
			Average:	24

Table 2.--Dissolved oxygen controls on the flowing-water apparatus used in measuring rate of oxygen consumption

Time	Determination No.	Temperature	Rate of flow	O_2 1/	
				Inlet	Outlet
		°C.	l./hr.	cc./l.	cc./l.
9:05 AM	1	23.8	14.52	4.64	4.66
9:45	2	24.0	14.52	4.62	4.62
10:30	3	23.8	14.52	4.64	4.66
11:00	4	23.8	14.52	4.69	4.66
11:35	5	23.8	14.52	4.78	4.72
1:00 PM	6	23.8	14.46	4.82	4.90
1:30	7	24.0	14.40	4.90	4.84
2:45	8	24.0	14.40	4.96	4.93
3:25	9	24.0	14.29	5.04	4.98
4:30	10	23.8	25.71	4.78	4.74
5:00	11	23.8	25.71	4.82	4.78
6:00	12	23.5	10.78	4.91	4.84
7:00	13	23.5	10.59	4.92	4.86

1/ All values are the average of two titrations.

Serial Determinations of Metabolic Rate: 24-Hour Experiments

Procedure.--Preliminary oxygen consumption tests indicated that a more or less consistent level of metabolic activity was reached after 1 to 2 hours in the container. It is not claimed that this represents a "basal" level of metabolism for iao, since the fish are not at complete rest, and furthermore it is obvious from the experiments described below that there is considerable fluctuation from hour to hour in the rate of oxygen uptake. It appears, however, that any great increase in metabolic rate due to the handling of the fish in setting up the experiment is dissipated after 1 to 2 hours.

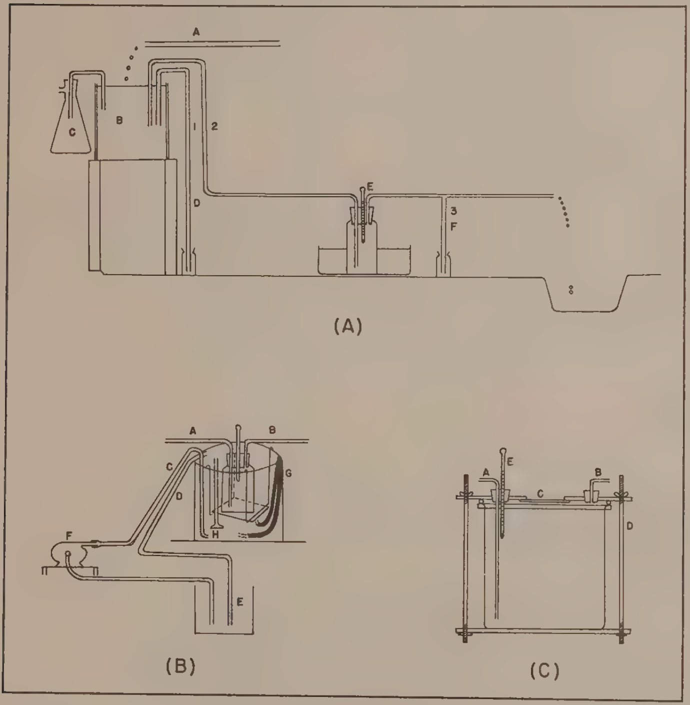

Figure 2a.-- Diagram of the apparatus used for measuring rate of oxygen consumption in iao. A - sea water line; B - reservoir; C - overflow jar; D - siphon for inlet samples; E - thermometer; F - connection for outlet samples. 1, 2, and 3: adjustable hose clamps.

Figure 2b.-- Assembly used for obtaining different temperature levels. A - inlet to experimental container; B - outlet from experimental container; C - inlet to copper coils; D - outlet from copper coils; E - cold bath; F - centrifugal pump; G - heating unit; H - stirring rod.

Figure 2c.-- Diagram of the experimental container used in the flow rate experiments. A - inlet to experimental container; B - outlet from experimental container; C - plastic observation window; D - threaded brass rod; E - thermometer.

In the actual experiments, 10 or more fish were carefully transferred to the jar and water was allowed to flow for 1 hour with the lid removed. The rubber cork with its connections was then inserted and the flow rate was adjusted to 12 liters/hour. Water samples were taken at 1-hour intervals for the first 3 or 4 hours, and approximately at 2-hour intervals thereafter.

Results.--The results of three successful 24-hour experiments, all performed in January and February of 1952, are reported in table 3 and figure 3. Although the data are quite variable, they seem to point to the absence of consistent diurnal cycles in the metabolic rate. In experiments 2 and 3, the rate of oxygen consumption fluctuates irregularly for about 6-8 hours, and then undergoes a slow, but nonetheless noticeable, decline for the remainder of the experiment. In both experiments, there is at the end of the 24 hours a small rise in the metabolic rate for which there is no apparent explanation. These tests, then, show only that there is an irregular, apparently non-cyclic, fluctuation in metabolic rate during the first 24 hours in the jar. Attention is called to the marked rise in oxygen consumption which occurred at

Table 3.--Serial measurements of metabolic rate (cc. /gm. /hr.) in iâo

Experiment 1

Number of fish: 18
Total weight: 15.9 gm.
Average length: 42 mm.
Range in length: 20-52 mm.

Time of day	Oxygen consumption	Temperature
	cc. /gm. /hr.	°C.
1215	.358	25.0
1315	.322	25.5
1410	.338	25.5
1800	.283	25.0
2300	.257	23.5
0215	.302	23.3
0640	.244	23.0
0835	.322	23.8
1045	.288	24.6
1150	.285	25.2

Experiment 2

Number of fish: 19
Total weight: 21.1 gm.
Average length: 47 mm.
Range in length: 40-55 mm.

Time of day	Oxygen consumption	Temperature
	cc. /gm. /hr.	°C.
1200	.288	25.0
1300	.230	25.4
1415	.298	25.0
1510	.313	25.0
1715	.269	25.0
2015	.426	24.5
2300	.263	24.0
0530	.258	23.5
0800	.204	24.0
1100	.209	24.4
1200	.230	24.5

Experiment 3

Number of fish: 20
Total weight: 21.1 gm.
Average length: 46 mm.
Range in length: 38-57 mm.

Time of day	Oxygen consumption	Temperature
	cc. /gm. /hr.	°C.
1100	.330	25.0
1200	.377	25.0
1300	.313	25.3
1515	.408	25.5
1700	.376	25.3
1915	.392	24.5
2100	.324	24.5
2400	.386	24.0
0300	.380	24.0
0600	.342	24.0
0915	.298	24.0
1115	.329	24.0

2000 hours in experiment 2. The fish might have been disturbed at this time because of frequent switching on and off of lights in adjacent rooms. The pattern for experiment 1 deviates from that of the other two experiments, possibly because of greater fluctuations in the temperature of the water (table 3). The results of this series, at any rate, are to be interpreted cautiously.

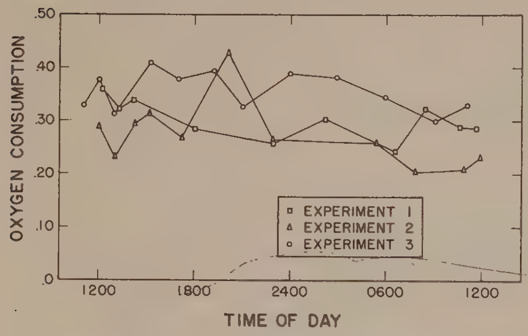

Figure 3.--Rate of oxygen consumption (cc./gm./hr.) in iao over a 24-hour period.

Influence of Temperature on Rate of Oxygen Consumption

Procedure.--With the arrangement shown in figure 2b, it was possible to raise the temperature in the container by approximately 2° intervals and keep it practically constant at any one level. The average variation in temperature was 0.3°C., the maximum variation in any test being 0.5°C. All experiments were begun at 19°C., at least 2 hours being taken to lower the temperature to this value. One set of samples was withdrawn at each temperature level, not less than 1/2 hour after the temperature reached the desired value. Fish used ranged in length from 34-50 mm., the average length of fish in each experiment ranging from 42-48 mm. The tests were run over a 10-day period in October 1951, during which time the temperature in the stock tanks was about 26°C.

Results.--The curve of temperature versus rate of oxygen consumption (fig. 4) resembles those found for other fish (e.g., Ege and Krogh 1914; Wells 1935a; Haugaard and Irving 1943). It rises slowly at first, the slope of the curve being somewhat steeper at the higher temperatures. Over the range in temperatures tested (19°-29°C.) there is an approximately twofold increase in the rate of oxygen consumption. Wells (1935a) has pointed out that small Fundulus show a more pronounced response to temperature changes than larger fish; however, the occasional presence of smaller iao (34-37 mm.) in the present experiments did not appear to alter the pattern of response to temperature. Knowing that the previous temperature history of the fish (acclimatization temperature) can markedly affect subsequent response to temperature changes (Wells 1935b, c; Sumner and Doudoroff 1938; Sumner and Lanham 1942), this factor was controlled as far as possible by running the experiments during one month (October) on fish which had been kept for some time at about 26°C.

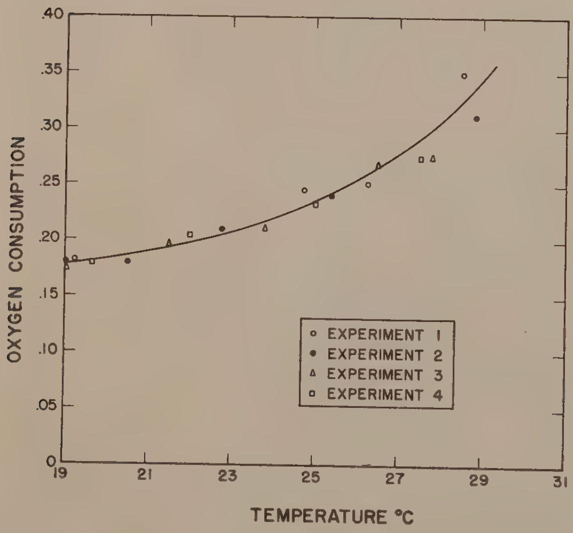

Figure 4.-- Rate of oxygen consumption (cc./gm./hr.) at different temperatures.

Influence of Flow Rate and Numbers of Fish upon the Metabolic Rate

Procedure.--In a typical experiment, the approximate desired number of fish were transferred to the experimental jar (fig. 2c), the flow was adjusted to an intermediate value, and about 1 hour was allowed for the fish to "settle down" in the container. The lid was then inserted and the flow adjusted to the highest value tested. On hour later, two consecutive sets of oxygen samples (in a few instances only one set of samples was taken) were withdrawn, and the flow was then lowered to the next value in the series. Flows ranging from 7 to 37 liters/hour were tested in conjunction with aggregations of fish ranging in number from 20 to 132 or, in terms of concentration per unit volume, 7 to 44 fish per gallon. A the latter density the vessel was definitely crowded, but there was no indication of abnormal behavior, such as changes in schooling pattern, etc. by the fish. The experiments were run in the morning and early afternoon, with an average duration of 4 to 6 hours. All but three tests were performed in August and September (1951) at temperatures of 27°-28°C. The size of the containe in itself appeared to keep the temperature from fluctuating and no temperature bath was deemed necessary. Fish of essentially the same size were used in all of the summer experiments, but somewhat larger fish were employed in the few winter tests.

Results.--The complete results are presented in table 4a. Figure 5 is drawn from the summer data and the points represent, where possible, the average of two values at each flow tested. The high values from experiment 4 are not included in the figure. In this experiment, th fish were initially extremely active and their behavior was not considered normal. Referring to figure 5 on the relation between flow rate and rate of oxygen consumption, curve 1 represents aggregations of 20 to 44 fish, curve 2 aggregations of 75 to 83 fish, and curve 3 applies to a single experiment using 132 fish.

For small aggregations of iao (20-45 fish), the rate of oxygen uptake is seen to increase linearly with increase in flow rate within the limits tested. At the lowest and highest flows, there is remarkable agreement in metabolic rate between the different lots of fish, with more variability evident at the intermediate flows. For comparable amounts of fish, tested in November (experiments 11 and 12), the influence of flow rate upon oxygen consumption is less striking; obviously, however, more experiments would be necessary to establish this point. The cause of this apparent difference in the behavior of summer and winter fish may be the cooler temperatures but attention is also called to the fact that larger fish were used.

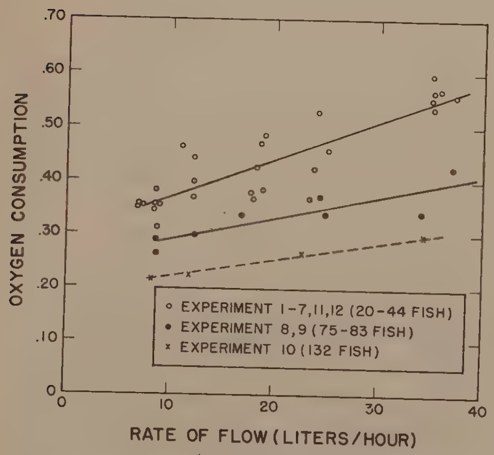

Figure 5.--Rate of oxygen consumption (cc./gm./hr.) in iao at different rates of flow (liters/hour). Regression coefficient for curve 1, .00735; for curve 2, .00412.

With 75 to 83 fish in the container, the relation of flow rate to oxygen consumption is much like that for small aggregations, though the effect appears to be less pronounced. More striking is the fact that the overall rate of oxygen uptake is lower. In experiment 10, where 132 fish were used, the level of oxygen consumption is again lower, but attention is called to the slightly lower temperature at which the experiment was performed.

A field trial, testing the influence of flow rates, was performed in the bait-well of the Territorial Fish and Game vessel Makua. Slightly over 2,000 grams of "mixed" bait (both nehu and iao) was used, giving a density of about 5 fish per gallon, roughly comparable to the minimum density used in the laboratory experiments (7 fish per gallon). The results, plotted in figure 6, show considerable fluctuation but bear some qualitative resemblance, at least, to the laboratory results. The large fluctuations observed may be due primarily to the inadequacies of field sampling.

Table 4a.--Rate of oxygen consumption (cc./gm./hr.) of iao at different rates of flow, in conjunction with varying quantities of fish. Experiments 1-10 were performed in August and September, and experiments 11 and 12 in November

Experiment No.	Number of fish	Total weight	Average length	Average temp.	Range in temp.	Rate of flow (l./hr.)					
						35-37	23-25	17-19	11-12	9	7-8
		gm.	mm.	°C.	°C.						
1	22	20.0	43	26.6	1.0	.588	-	.488	.476	.386	.354
						.606	-	.450	.447	.382	.350
						x̄.597	-	.469	.462	.384	.352
2	39	26.5	41	26.9	1.0	.547	-	.424	.387	.348	.356
						.519	-	.424	.402	.351	-
						x̄.533	-	.424	.395	.350	.356
3	30	21.7	42	28.0	0.5	.526	-	.343	.360	-	.345
						.571	-	.286	.372	-	.359
						x̄.549	-	.315	.366	-	.352
4	26	19.0	42	27.6	0.7	?.893	.487	.481	-	.355	-
						?.964	.554	.481	-	.355	-
						x̄.929	.521	.481	-	.355	-
5	44	28.0	41	28.3	0.5	.554	.465	.360	.428	Temp. rising, fish excited	
						.579	.438	.367	.460		
						x̄.567	.452	.364	.444		
6	20	15.2	42	27.3	0.8	.533	.383	.400	-	.358	-
						.580	.353	.362	-	.335	-
						x̄.557	.368	.381	-	.347	-
7	28	21.0	42	27.0	0.4	.543	.429	.374	-	.313	-
						.578	.417	.381	-	.309	-
						x̄.561	.423	.378	-	.311	-
8	75	55.2	41	28.4	0.0	.426	.367	-	.299	.291	-
						.419	.372	-	.298	.290	-
						x̄.422	.370	-	.298	.290	-
9	83	51.4	39	28.4	0.1	.333	.338	.331	-	.263	-
						.346	.338	.334	-	-	-
						x̄.340	.338	.332	-	.263	-
10	132	116.3	43	26.1	0.2	.289	.263	-	.220	.215	-
						.295	-	-	-	-	-
						x̄.292	.263	-	.220	.215	-
11	30	34.5	47	24.8	0.1	.285	.300	-	.246	.241	-
						.285	-	-	-	-	-
						x̄.285	.300	-	.246	.241	-
12	35	44.4	48	24.3	0.7	.242	.218	-	.197	.183	-
						.220	-	-	-	-	-
						x̄.231	.218	-	.197	.183	-

Discussion

A striking feature of the serial observations of rate of oxygen consumption (table 3) is the great variability from hour to hour. Such fluctuations are apparently not uncommon, however, having been observed by several workers (Chapman 1939; Clausen 1936; Shlaifer 1939; Wells 1935a). The following statement of Wells (1935a) is perhaps apropos: "Duplication of results with the same animals at two different times is not a measure of the efficiency of the apparatus, nor is a failure to duplicate results a reflection upon the method." Krogh (1916) mentions that the respiratory exchange in a normal animal may vary 100 percent or more. Over the 24-hour period during which serial observations were made, no consistent rhythms in metabolic rate were evident. Daily cycles in metabolic rate have been claimed for a few freshwater fish (Clausen 1936; Oya and Kimata 1938; Higginbotham 1947) but have not received extensive confirmation.

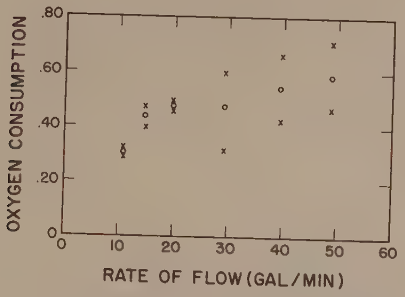

Figure 6.--Results of a field experiment testing the influence of flow rate (gal./min.) on rate of oxygen consumption (cc./gm./hr.). Open circles represent the average of two determinations of oxygen consumption (represented by crosses) at each flow.

The temperature-oxygen consumption curve (fig. 4) in general resembles those for other fish but must, of course, be interpreted entirely upon its own merits, particularly since a relatively narrow temperature range was studied. The curve may be said to represent an experimentally determined relationship of temperature to rate of oxygen consumption in iao ranging in size from 34 to 50 mm. for the temperature interval 19°-29°C. In view of the apparently valid arguments of Ege and Krogh (1914) and Wells (1935a) against the unrestricted use of Van't Hoff's Q_{10} and the Arrehenius relation, no attempt was made to calculate either Q_{10} values or "thermal increments." Ege and Krogh, for example, found that Q_{10} varied from 9.8 at 0°-5°C. to 2.2 at 23°-28°C. in the goldfish.

At the higher temperatures in the range tested, the effect of temperature upon metabolic rate appears somewhat more pronounced. Since the local fishery is conducted almost entirely during the summer and early fall, when water temperatures often rise to 27°-28°C. and higher, it may be advisable to watch for sudden changes in the water temperature of the live-wells. Even a small rise in temperature might considerably increase the activity and consequently the rate of oxygen consumption of the fish.

That the rate of oxygen consumption should rise with increase in rate of flow is perhaps not surprising, inasmuch as the fish would presumably exert more energy in swimming as the current of water through the jar increases in intensity. In curve 1 (fig. 5), representing small aggregations of fish and based on the most extensive collection of data, oxygen consumption increases linearly with flow rate over the range from 7 to 37 liters/hour. The points appear less scattered at the extreme flow values. This may be a chance variation or the fish, for some reason, may exhibit a uniform metabolic response to the environment at the extreme flow rates. This explanation is easier to accept in the case of the high flow values (35-37 liters/hour), where the fish might all be exerting approximately the same amount of energy in maintaining their position against the strong current.

When larger numbers of fish are used (curve 2, fig. 5), the overall level of metabolism is lower. An analysis of covariance (tables 4b and 4c) on the data making up curves 1 and 2 yields the following statistical conclusions: 1) the difference between the mean values for metabolic rate, adjusted to a common flow value, of group 1 (20-45 fish, adjusted mean 0.431 cc./gm./hr.) and group 2 (75-83 fish, adjusted mean 0.320 cc./gm./hr.) is highly significant ($P < 0.01$), indicating

Table 4b.--Analysis of covariance and test of significance of adjusted mean oxygen consumption values for group 1 (20-45 fish) and group 2 (75-83 fish)

Source of variation	Degrees of freedom	Errors of estimate		
		Sum of squares	Degrees of freedom	Mean square
Total	36	0.145	35	-
Groups	1	-	-	-
Within groups (error)	35	0.069	34	0.0020
For testing significance of adjusted means	-	0.076	1	0.076 **

**Significant at 1-percent level ($P < 0.01$).

Table 4c.--Analysis of errors of estimate from the average regression within groups

Source of variation	Degrees of freedom	Errors of estimate	
		Sum of squares	Mean square
Deviations from average (error) regression within groups, table 4b	34	0.069	-
Deviations from individual groups regressions	33	0.063	0.0019
Differences among group regressions	1	0.006	0.006

that the drop in oxygen consumption is probably a real one; and 2) the difference between the slopes of the two curves is not significant (table 4c), indicating that the effect of flow rate on oxygen consumption is similar regardless of the numbers of fish tested.

The drop in metabolic rate with larger groups of fish deserves further discussion. Schuett (1933) and Shlaifer (1938) both point out that 2 to 4 goldfish in a container consume significantly less oxygen per unit weight than single fish. A similar "group effect" has been observed by Geyer and Mann (1939a, b) in Perca fluviatilis. All these authors find that the effect disappears when the size of the container is increased in proportion to the increase in numbers of fish. The present data are inadequate to justify anything but tentative conclusions. The decrease in metabolic activity is perhaps due to changing intensity of motion caused by the reduction in space available per fish. No evidence is available, however, attesting to the possible influence on the metabolic rate of accumulated excretory products and other gases, particularly when large numbers of fish are used. This aspect should be investigated further. Geyer and Mann (1939a) are of the opinion that a decrease in oxygen concentration with greater numbers of fish is responsible for the "group effect." This factor can probably be neglected in the present work since, as will be pointed out in the next section, oxygen consumption in the iao is independent of concentration down to at least 2.5 cc./l. In the flow-rate experiments, the oxygen concentration of the outlet samples in no case fell below 2.5 cc./l.

It is of interest to evaluate these laboratory findings in terms of the problems involved in keeping bait alive in fishing vessels. The lowering of metabolic rate with large numbers of fish might be construed to mean that increasing the number of fish in a live-well leads to more efficient maintenance. This may be true, but more data are necessary to substantiate such a view. Furthermore, if too many fish are present, the oxygen content of the water obviously may be reduced to near the lethal value, which, as will be seen shortly, is about 1.0 cc./l. for iao. For nehu, the preferred baitfish, the limited data available indicate a lethal value of about 2.0 cc./l. (table 7). Those boats having pumps could handle more fish by increasing the flow rate through the live-wells, but this in itself causes an increase in activity and oxygen consumption (fig. 5). In order to arrive at the best combination of flow rates and aggregation size the present laboratory experiments should be followed up by field tests, possibly using the same flow rates and densities of fish.

METABOLIC REGULATION IN THE IAO

In summarizing the literature pertaining to the relationship between rate of oxygen consumption and the dissolved oxygen content of the water, it is apparent that some fish are markedly affected by changes in external oxygen while others are not. Gaarder (1918) found a very slight dependence of oxygen consumption on oxygen concentration in the carp. Powers and Shipe (1928) claim that for herring, coho salmon, and viviparous perch a decrease in the amount of dissolved oxygen caused a proportional decrease in the rate of oxygen consumption. According to Hall (1929), the degree of metabolic regulation depends on whether the fish is an active or sluggish species, the former showing metabolic independence and the latter complete dependence on the oxygen concentration of the medium. In any event, small changes from the normal oxygen content of the water probably do not affect oxygen uptake in most fish (Keys 1930a; Wells 1935a; Lindroth 1940; Fry and Hart 1948), but an oxygen level is eventually attained below which metabolic adjustment fails and the rate of oxygen uptake begins to decrease. This "critical level" varies with species and with temperature (Lindroth 1940; Fry and Hart 1948; Graham 1949).

One means by which fish accomplish metabolic regulation is an increase in the frequency of breathing movements. This compensates for the fall in oxygen concentration by permitting more water per unit time to flow past the gill surfaces. Several workers (Westerlund 1906; Winterstein 1908; Wells 1913; Gardner and King 1922; Belding 1929; Wilding 1939) have incidentally observed an increase in the rate of opercular movement, to a greater or lesser degree, with a decrease in the oxygen content of the water. On the other hand, there are few works in which both the rate of oxygen consumption and breathing movements are analyzed and their interrelations discussed. Notable exceptions are papers by Meyer (1935), who worked with Uranoscopus scaber, and van Dam (1938), who worked on eel and trout. Both workers determined not only breathing rate, but breathing depth and ventilation volume in relation to oxygen concentration. Van Dam found that the eel (Anguilla vulgaris) showed much better metabolic regulation than the trout (Salmo shasta).

The above discussion points to the importance of determining the degree of metabolic regulation in any fish whose oxygen relations are being investigated. In this section the relationship of metabolic rate to oxygen concentration is analyzed, and to supplement these data the rate of opercular beat is determined at various oxygen values.

Apparatus

To introduce water of different oxygen concentrations, several modifications in the basic experimental assembly were necessary. Figure 7 shows the modified assembly set up for experiments on breathing movements. When the apparatus was used to determine rate of oxygen consumption, a wide-mouth gallon jar was substituted for the glass tube shown suspended in the water bath. The carboy on the left contained water low in oxygen, obtained by bubbling through nitrogen gas, and the one on the right contained normal sea water. Water from both carboys was joined by a "Y" tube into a single flow entering the overflow flask. Oxygen samples were taken in the manner described earlier, with the exception that inlet samples were siphoned from the overflow flask. Control tests indicated only negligible variation in dissolved oxygen content between carboy, overflow flask, and the outlet of the experimental chamber.

Relation between Dissolved Oxygen Concentration and the Rate of Oxygen Consumption of the Iao

Procedure.--Since the supply of low-oxygen water from the carboy was limited, the plan was to test several lots of fish, each at a different oxygen level, from 7 to 14 fish being used in each experiment. After the fish were in the container, normal sea water was circulated through the jar for 1 hour. Two consecutive sets of oxygen samples were then taken from which the average rate of oxygen consumption in normal sea water, i.e., the "control" value, was calculated. The normal sea water line was then pinched off and oxygen-poor water was permitted to circulate through the system. After 30 minutes, a set of oxygen samples was taken and the metabolic rate at the new oxygen level was determined.

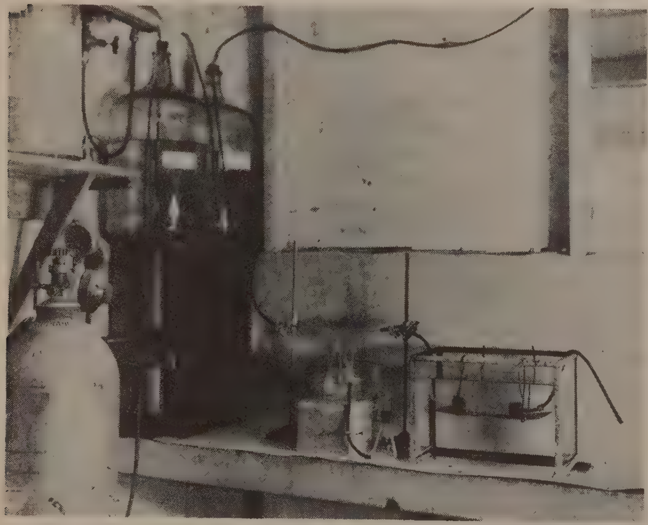

Figure 7.--Apparatus used in measuring oxygen consumption and breathing rate at different oxygen concentrations. The apparatus is shown assembled for breathing rate experiments. Detailed description in text.

The experiments were all performed during morning hours at temperatures generally between 24° and 25°C. A fairly wide range of sizes was employed, the average length of fish in each test ranging from 37 to 49 mm.

Results.--The relationship between oxygen consumption and oxygen concentration (fig. 8) shows that the rate of oxygen uptake fluctuates about a constant level down to low values of oxygen but eventually starts to fall, the decline becoming more rapid as the lethal value of oxygen is approached. Complete data are reported in table 5. Unfortunately, few points are available in the region where the decline in oxygen consumption begins and it is difficult to establish anything like a definite "critical" level of oxygen. At best, it can be stated that the critical level lies between 1.5 and 2.5 cc./l. Some of the scattering of points, particularly in the first part of the curve, may be attributed in part to the rather large range of sizes used. On the other hand, tests in which a great many small fish were used did not indicate, on the whole, a greater or lesser decrease in oxygen consumption compared with tests in which many large fish were used. (Compare, for example, experiments 7 and 14, table 5.) Since the experiments were performed over a fairly narrow range of temperatures, it appears unlikely that the critical level would be shifted due to differences in temperature between tests.

Table 5.--Rate of oxygen consumption (cc./gm./hr.) at various oxygen concentrations

Experiment No.	Total weight of fish used	Range in length	Average length	Temperature	Average control O_2 value	Rate of oxygen consumption (control)	Average experimental O_2 value	Rate of oxygen consumption (experimental)	Decrease in consumption from control
	gm.	cm.	cm.	°C.	cc./l.	cc./gm./hr.	cc./l.	cc./gm./hr.	cc./gm./hr.
1	8.1	44-57	49	23.5	4.21	.330	1.15	.079	.251
2	7.0	41-54	44	23.6	4.13	.428	1.09	.166	.262
3	6.8	44-56	48	24.0	4.14	.354	1.14	.107	.247
4	9.1	41-51	46	24.8	4.06	.417	1.25	.204	.213
5	10.6	42-59	47	24.4	3.93	.374	3.42	.304	.070
6	10.0	36-51	45	25.0	3.95	.522	1.12	.209	.313
7	12.4	36-52	44	25.0	3.82	.506	2.66	.369	.137
8	9.6	36-55	44	25.0	3.96	.416	2.22	.292	.124
9	9.0	35-52	46	25.2	4.12	.446	3.02	.394	.054
10	9.9	38-56	46	24.2	4.08	.448	3.05	.358	.090
11	8.2	30-51	46	24.8	3.91	.423	3.86	.346	.077
12	8.0	36-50	45	25.6	4.09	.437	3.90	.393	.044
13	9.7	43-51	48	24.0	4.07	.353	1.14	.144	.209
14	6.1	32-49	39	25.5	3.86	.484	1.12	.161	.323
15	5.3	33-44	39	26.0	3.82	.478	1.44	.308	.170
16	5.6	34-45	37	25.8	4.09	.420	2.71	.328	.092
17	7.2	38-52	39	26.8	5.39	.417	3.10	.417	.000
18	6.9	35-46	41	25.0	3.86	.448	1.58	.258	.190
19	9.3	33-52	41	24.5	3.88	.347	1.84	.261	.086

Frequency of Opercular Movements in Iao at Different Oxygen Concentrations

Procedure.--To obtain accurate gill movement counts, it was necessary to immobilize the fish, which was done by placing it in a clay mount on a microscope slide with only the head and gill cover protruding. With practice in the technique, handling could be reduced to a minimum. The immobilized fish was placed in a finger bowl of sea water and, if it did not work free and if it assumed a regular opercular beat, it was quickly transferred to the glass tube immersed in the water bath. Normal sea water was allowed to flow through the tube for about 30 minutes before counts were taken. In these experiments it was possible to test an individual fish at more than one oxygen level, the different levels being obtained by mixing appropriate amounts of water from the two carboys. Five determinations of the time required for 50 beats (from which the beats/minute was calculated) were taken at each oxygen value.

The reliability of the method was tested by taking counts in normal sea water over a 90-minute period (the maximum duration of any experiment) on two fish. The results indicated little fluctuation in normal opercular rhythm. For each fish 15 separate counts were taken, the means and standard deviations being 215 ± 4.2 (fish 1) and 213 ± 3.7 (fish 2).

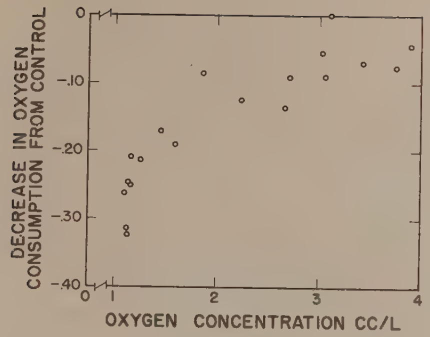

Figure 8.--Change in rate of oxygen consumption (cc./gm./hr.) with a decrease in the oxygen content of the water. Ordinate represents the decrease in rate of oxygen consumption from control values.

The experiments were performed in February of 1952 and 1953, at temperatures of 23°-24°C. (average 23.9°C.). Fish used ranged in length from 39 to 62 mm. and in weight from 0.56 to 2.46 gm., weight being taken to the nearest 0.01 gm. on a Roller-Smith torsion balance after 1 week's preservation in 10-percent formalin.

Results.--From the eye-fitted curve (fig. 9) it is seen that as the oxygen content of the water falls, the respiratory rate rises, slowly at first, then more rapidly, to a peak beyond which it slowly decreases. The maximum breathing rate is attained probably somewhere between 2.0 and 2.5 cc./l.--the peak in the curve is not well defined, principally because of the very gradual subsequent decrease in breathing rate. The points are widely scattered in the first part of the curve and this is reflected in the behavior of the fish. As the oxygen concentration is lowered the fish at first show some agitation and occasional irregular breathing. Later, at the very low oxygen values, breathing is slower and more regular. No quantitative measurements of breathing-depth were made, but the fish were observed to breathe deeper, as well as faster, as the oxygen content was lowered. Deep breathing continued, in several cases, after breathing frequency began to diminish.

Discussion

Comparison of the relationship of oxygen consumption (fig. 8) and opercular rhythm (fig. 9) to the oxygen content of the water is experimentally difficult for at least two reasons. For one thing, it was necessary to use different techniques in each series of tests. In the experiments on oxygen consumption each group of fish could be tested at only one oxygen level, whereas in the breathing rate experiments a fish could be run through a whole series of oxygen values. Furthermore, the points are somewhat scattered in both cases, especially at the higher oxygen concentrations, and it is difficult to determine precise oxygen values below which rate of oxygen consumption and breathing rate decline. With these precautions in mind, it is still perhaps safe to say that both breathing rate and oxygen consumption begin to decrease at approximately the same level of oxygen, somewhere between 1.5 and 2.5 cc./l., the implication being that the fall in breathing rate contributes, in part at least, to the fall in oxygen consumption. From the standpoint of the livebait fishery, a "danger" point might be placed at 2.5 cc./l. If the oxygen content of the water in the live-wells falls much below this value, the fish will more than likely not be getting sufficient oxygen to maintain normal metabolism.

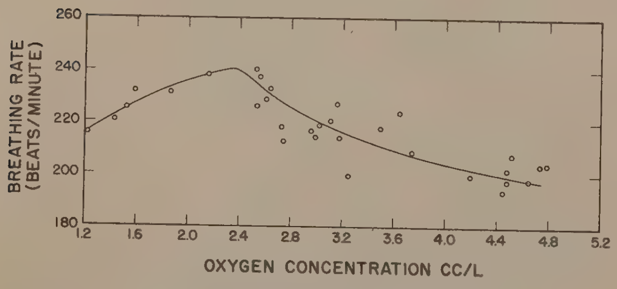

Figure 9.--Breathing rates (beats/minute) at different oxygen concentrations.

LETHAL VALUES OF OXYGEN

A major problem in the confinement of baitfish is the possible depletion of oxygen to a level below that tolerated by the fish. Suehiro (1951) found that newly introduced "wild" bait congregated densely at the surface, and a localized depletion of oxygen to below the lethal value occurred, regardless of an increase in the amount of water circulated through the tank. Information on lethal values of oxygen is widely scattered through the literature and there are few extensive experimental investigations of the subject. In view of these considerations, it was thought worthwhile to determine the lethal value of oxygen for the local species of baitfish. Both individual fish and groups of 10 to 15 fish were asphyxiated in closed containers. In addition, the effect of temperature on the lethal value of oxygen was determined, single fish being employed for these tests. Complete cessation of all movements, breathing or otherwise, was taken as indicating the death of the fish, the validity of this criterion being evidenced by the fact that no recoveries were obtained upon return to normal sea water.

With the exception of the first summer's experiments, all oxygen samples were analyzed by the Rideal-Stewart modification of Winkler's procedure. A comparison between the modified and unmodified methods is reported in table 6. The oxygen samples were siphoned off simultaneously from large, sealed Erlenmeyer flasks in which fish had been using up the dissolved oxygen for some time. The mean difference in the values obtained by the two methods is not significant (P = 0.08), but the discrepancy in some of the trials is pronounced; to be safe, therefore, it was decided to use the Rideal-Stewart procedure.

Table 6.--A comparison of the Rideal-Stewart and unmodified Winkler procedures for determining the dissolved oxygen content of water in which fish have extensively respired

Experiment No.	Number of fish	Oxygen at end of experiment (cc./l.)		
		Rideal-Stewart	Unmodified	Difference
1	5	2.40	2.50	-0.10
2	6	2.48	2.46	0.02
3	7	1.45	1.38	0.07
4	4	3.08	3.06	0.02
5	4	1.38	1.08	0.30
6	4	2.46	2.48	-0.02
7	3	1.02	0.94	0.08
8	3	1.30	1.16	0.14
9	2	1.28	1.20	0.08
10	3	1.32	1.24	0.08
11	4	1.10	1.12	-0.02
			Mean	= 0.059
			Standard Error of the Mean	= 0.031
			"t"	= 1.90
			P	= 0.08

Lethal Values of Oxygen for Nehu and Iao: Experiments Using Single Fish

Procedure.--For most of these tests Florence flasks of about 540 ml. capacity were employed as experimental containers. Occasionally, depending on the size of fish used, larger or smaller flasks were necessary. The flasks were surrounded by white cloth to prevent the fish from becoming unduly excited, and a small piece of screening was placed in the neck to keep the fish from entering this portion of the flask.

After the fish was transferred to it, the flask was filled, stoppered, and immersed to its neck in a water bath. Initial oxygen samples were obtained from flasks immersed in the water bath but containing no fish. After all movement of the fish in the experimental jar had ceased, an oxygen sample was quickly siphoned off, the water being allowed to circulate through the bottle for a few seconds after it was filled. In some of the earlier experiments a 50-ml. sample was then taken for pH determination, leaving about 50-70 ml. in the flask. The length of the fish, from the tip of the snout to the end of the vertebral column, was taken to the nearest millimeter, and with the exception of some of the earlier experiments, the fish were preserved in 10-percent formalin to be weighed later on a Roller-Smith torsion balance.

As a check on the possibility of errors due to absorption of oxygen during siphoning, water samples of low oxygen content were siphoned off from two flasks, one with a layer of mineral oil and the other without the layer. The difference in amount of dissolved oxygen between these samples was within the error of the Winkler procedure.

The experiments on iao were divided into two groups, a summer series and a winter series, reported respectively in tables 8a and 8b. Eleven experiments were performed with nehu, all in the late spring and summer of 1950, and these are reported in table 7.

Results.--Considerable variability was evident in the results, as might be expected in collecting data on individuals. The mean and standard deviation of all the summer lethal values for iao (table 8a) was 1.10 ± 0.22 cc./l. and that of the winter values 0.96 ± 0.18 cc./l., with mean temperatures of 25.6 ± 0.9°C. and 21.9 ± 0.6°C. respectively. The difference between these mean values, when tested statistically by analysis of variance (table 8c), was found to be significant at the $P = 0.05$ level. The mean lethal value for nehu was 2.02 cc./l. with a standard deviation of 0.35 cc./l., much larger than that for either series on iao. The great variability of the nehu data was probably a consequence of the fish's behavior when confined to the experimental flask. In contrast to iao, nehu generally remained greatly agitated throughout the experiment and some undoubtedly became injured, thus causing an abnormally high lethal value of oxygen.

Weights were not available for all the fish used, but the data on hand show no significant relationship between weight of fish and the lethal value of oxygen. Regression lines for both summer and winter data did not differ significantly from zero ($P = 0.1$ in both cases). At best, a slight trend towards greater resistance to oxygen deficiency in the larger fish was indicated.

It seems fairly certain that the death of the fish in these tests was due to lack of sufficient oxygen and was not affected by a lowering of the pH during the course of the experiment. Hydrogen ion concentration was measured at the end of the earlier experiments and was never less than 7.80, averaging 7.87. The water in the stock tanks often showed pH values of this magnitude.

Some evidence is available (experiments 16, 17, and 18 of the winter series) to indicate that lethal values of oxygen are about the same regardless of the initial oxygen content of the water. This point, however, needs further investigating.

Table 7.--Lethal values of oxygen for nehu

Date	Experiment No.	Temperature	Duration of experiment	O_2 (cc./l.)		Volume of jar	Length of fish
				Initial	Final		
		°C.				cc.	mm.
3-9-50	*1	22.9	1hr40min	5.04	2.54	1070	-
3-17-50	*2	24.7	1hr45min	4.95	2.42	"	-
3-18-50	*3	25.0	2hr15min	5.36	1.87	"	-
3-21-50	*4	24.8	1hr47min	4.90	2.41	535	-
4-22-50	*5	26.5	2hr	3.91	2.30	"	-
8-23-50	6	25.6	4hr35min	4.73	1.96	"	34
8-24-50	7	25.0	3hr55min	4.68	1.64	"	37
"	8	"	7hr10min	"	1.60	"	31
"	9	"	4hr45min	"	1.66	"	35
8-25-50	10	24.8	6hr40min	4.36	1.80	"	29
"	11	"	3hr45min	"	1.98	"	34
				mean 2.02 ± .35			

*Experiments performed at the Waikiki Marine Laboratory.

Table 8a.--Summer lethal values of oxygen for iao

Experiment No.	Temperature	Duration of experiment	O_2 (cc./l.)		Volume of jar	Weight of fish	Length of fish
			Initial	Final			
	°C.				cc.	gm.	mm.
*1	25.9	1hr12min	3.69	1.05	1070	-	-
*2	26.2	1hr22min	5.32	1.27	"	-	-
*3	25.7	1hr30min	6.20	1.38	"	-	-
*4	24.4	1hr05min	5.17	1.01	"	-	-
*5	24.5	1hr23min	5.48	1.28	"	-	-
6	27.3	3hr55min	4.60	1.58	535	-	37
7	27.0	6hr15min	4.50	1.28	"	-	30
8	24.3	8hr55min	4.67	0.94	"	-	25
9	24.0	7hr50min	4.67	1.11	"	-	28
10	26.0	6hr30min	4.72	1.20	"	-	31
11	27.1	2hr	4.38	0.87	"	-	58
12	27.1	2hr45min	4.38	0.86	"	-	50
13	25.3	2hr50min	4.44	1.08	"	1.06	45
14	25.3	1hr30min	4.44	0.75	"	2.80	60
15	25.3	3hr30min	4.44	1.17	"	0.75	41
16	26.5	3hr	4.43	1.41	250	0.57	39
17	25.0	3hr55min	4.36	1.02	"	0.43	36
18	25.2	6hr45min	4.33	1.18	535	0.60	37
19	25.2	4hr	4.33	1.20	"	0.96	44
20	25.1	5hr30min	4.50	0.63	"	1.10	45
21	25.1	4hr15min	4.50	1.18	"	1.10	46
22	25.1	6hr25min	4.50	0.88	"	0.80	42
23	25.1	3hr25min	4.50	1.07	"	1.34	49
mean	25.6 ± 0.9			1.10 ± 0.22			

*Experiments performed at the Waikiki Marine Laboratory.

Table 8b.--Winter lethal values of oxygen for iao

Experiment No.	Temperature	Duration of experiment	O_2 (cc./l.)		Volume of jar	Weight of fish	Length of fish
			Initial	Final			
	°C.				cc.	gm.	mm.
1	23.1	2hr45min	4.60	0.96	535	2.09	54
2	23.1	6hr	4.60	0.82	"	1.08	45
3	23.1	5hr15min	4.60	0.80	"	1.36	48
4	21.3	3hr30min	4.94	1.03	"	1.66	51
5	21.3	4hr30min	4.94	0.86	"	1.52	50
6	21.9	5hr	4.70	1.16	"	1.14	46
7	21.9	5hr05min	4.70	1.14	"	1.49	50
8	21.9	4hr10min	4.70	1.04	"	1.45	50
9	21.6	3hr10min	4.58	1.17	"	1.50	49
10	21.6	3hr10min	4.58	1.16	"	1.49	49
11	21.6	3hr45min	4.58	1.09	"	1.37	48
12	21.6	4hr30min	4.58	0.90	"	1.25	47
13	21.6	4hr05min	4.58	1.21	"	1.00	45
14	21.6	4hr20min	4.58	0.79	"	1.36	49
15	21.4	4hr15min	4.15	0.82	"	1.95	52
16	21.4	45min	1.10	1.02	"	1.06	43
17	21.4	3hr25min	2.01	0.78	"	1.35	47
18	22.3	4hr15min	2.96	0.50	"	1.98	53
mean	21.9 ± .6			0.96 ± .18			

Table 8c.--Analysis of variance of the data from the above two tables

Source of variation	Degrees of freedom	Sum of squares	Mean squares
Total	40	1.8995	-
Seasons	1	0.2152	0.2152*
Within seasons	39	1.6843	0.0431

*Significant at 5-percent level ($P < 0.05$).

Lethal Values of Oxygen for Iao: Experiments Using Several Fish

Procedure.--In these experiments, 10-15 fish (usually 14) were placed in a 1-liter aspirator jar with a side-opening close to the bottom for withdrawing water samples. Water was circulated through the container for 1 hour, at which time the fish were quiescent and appeared to be schooling normally. Circulation was then stopped, about 100 ml. was run out and replaced by mineral oil, after which the jar was securely stoppered. Three samples were taken in each experiment, after approximately one-third, one-half, and all of the fish had died. At the end of the experiment all fish were measured to the nearest millimeter. The tests were run in December 1951 and January 1952.

Results.--Table 9 gives the conditions and results of each experiment, and figure 10 shows graphically the relation between oxygen concentration and percentage of fish dead, the curve being fitted by the method of least squares, using a log-log transformation of the data. For those experiments employing 14 fish, the times to approximately 50-percent mortality are fairly similar, indicating more or less uniform behavior for the different lots of fish. Comparing the data with the winter lethal values of oxygen obtained from individual fish (table 8b), it is evident that the overall range in lethal values is nearly the same, being 0.55-1.30 and 0.50-1.21 cc./l. respectively. On the other hand, the mean value from table 8b (0.96 cc./l.) is higher than the mean of the values from the present experiments. Inspection of figure 10 indicates that, in the group experiments, practically all the fish died at oxygen concentrations between 0.55 and 0.85 cc./l. whereas figure 11, plotted from the data of table 8b, indicates, for the tests on individuals, a more even distribution over the range of lethal values of oxygen.

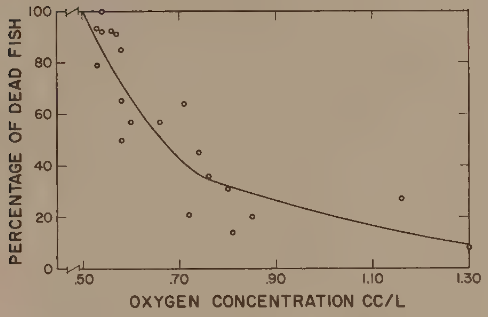

Figure 10.--Lethal values of oxygen for iao: experiments using several fish. Abcissa represents the oxygen content of the water; ordinate represents the percentage of fish dead at the various oxygen concentrations.

Effect of Temperature on Lethal Values of Oxygen for Iao

Procedure.--These tests, in which single fish were used, were performed in a constant temperature apparatus consisting of six compartments separated by tin plates with a thermostatically controlled heating coil in one of the end compartments and a similarly controlled refrigeration unit in the other. The water in the baths was agitated at intervals by compressed air. After allowing 4-5 hours to establish a constant gradient of temperature, the temperature in each of the baths rarely fluctuated more than 0.3°-0.4°C., with the hotter baths in general showing the most variability.

In the experiments, two Florence flasks, each containing one fish, were immersed in each temperature bath. Handling of fish and water sampling were done in the manner described in the previous sections. Excepting a few experiments at 18°C., all tests were made at temperatures ranging from 21° to 31.5°C. Preliminary tests indicated that iao die almost immediately at temperatures over 34°C. but, with the exception of a great increase in activity, appear to behave normally at 31°C. For the tests at 18°C. the fish were first gradually introduced to this temperature by placing a gallon jar containing five fish in the water bath used for the temperature versus oxygen consumption experiments (fig. 2b) and circulating cold water through the copper coils while a slow stream of sea water flowed through the jar. Final equilibrium at 18°-19°C. was reached after 3 to 4 hours, thus avoiding the shock of a sudden

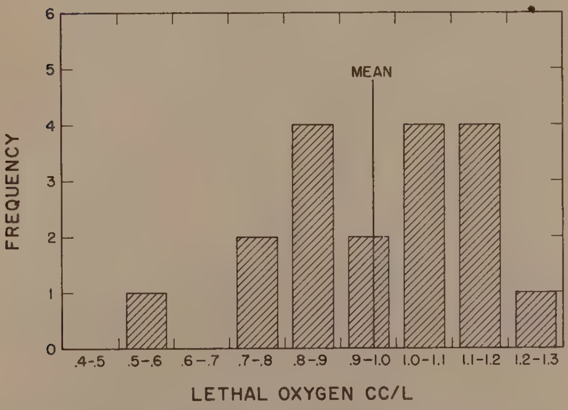

Figure 11.--Frequency distribution of winter lethal values of oxygen for iao, calculated from data of table 8b.

transfer to colder water. After 24 hours at 18°-19°C. no fish had died and all appeared to be in good condition.

Table 9.--Lethal values of oxygen for iao: experiments using several fish

Date	Experiment No.	Number of fish	Average length	Percent dead	O_2	Time for approx. 50% of fish to die	Temperature
			mm.		cc./l.		°C.
12-8-51	1	11	45	27	1.16	-	23.8
				64	0.71		
				91	0.57		
12-11-51	2	14	43	21	0.72	1hr50min	23.0
				57	0.66		
				100	0.54		
12-16-51	3	13	48	8	1.30	-	23.0
				31	0.80		
				85	0.58		
12-18-51	4	14	45	36	0.76	1hr40min	23.0
				79	0.53		
				100	0.54		
12-28-51	5	14	43	14	0.81	2hr15min	23.4
				50	0.58		
				92	0.54		
12-29-51	6	14	46	92*	0.56	2hr10min	22.4
1-3-52	7	10	49	45	0.74	-	23.4
				65	0.58		
				100*	0.54		
1-15-52	8	15	45	20	0.85	-	22.0
				57	0.60		
				93	0.53		

*All fish died within 5-10 minutes of each other.

Results.--The experiments were performed in January and February of 1951 and of 1952 and the fish used were therefore taken from waters ranging in temperature from 22° to 23°C. The results are presented in figure 12 and table 10, the points on the graph representing the average value for the two flasks in each bath. Lethal values of oxygen are seen to increase slowly at first (between 20.5° and 23°C.) and then more rapidly above 26°C. In spite of considerable variability in the results at each of the temperature levels, the overall trend is unmistakable. The apparent rise in the lethal value of oxygen at 18°C. is, unfortunately, based on the results of only two experiments and obviously a rigid interpretation cannot be given. Two things may be noted, however; first, the temperature was at least 3°C. lower than any temperature experienced by the iao in its natural environment; and secondly, the period of adjustment to this temperature was probably too short. Both factors could contribute to the high lethal oxygen value obtained.

Table 10.--Lethal values of oxygen for individual iao at different temperatures

Experiment No.	Temperature	Lethal O_2	Length of fish	Weight of fish	Duration of experiment
	°C.	cc./l.	mm.	gm.	
1	30.6	1.13	48	1.25	5hr50min
		1.18	48	1.34	5hr15min
	25.2	0.72	46	1.02	9hr10min
	22.0	0.70	40	0.62	11hr05min
2	31.0	0.94	49	1.52	3hr30min
		1.16	51	1.70	3hr
	26.1	0.74	47	1.27	3hr25min
	22.8	0.74	48	1.26	3hr20min
3	31.3	1.02	46	1.20	3hr15min
		1.12	49	1.46	2hr45min
	25.9	0.82	49	1.59	6hr40min
		0.84	50	1.62	4hr25min
	21.8	1.03	45	1.31	5hr30min
		0.58	50	1.70	6hr
4	30.5	1.21	46	1.20	1hr50min
		1.20	51	1.66	2hr13min
	25.8	0.91	54	1.99	2hr35min
	21.1	0.69	52	1.59	6hr40min
5	30.6	1.16	48	1.25	2hr45min
	27.6	0.97	54	2.17	2hr10min
		1.21	45	1.12	3hr
	25.2	0.91	50	1.41	3hr
		0.80	51	1.46	2hr40min
	20.8	0.78	51	1.54	5hr10min
6	27.8	0.96	56	1.79	2hr45min
		1.04	50	1.54	3hr05min
		0.99	50	1.50	4hr
	21.8	0.72	56	2.47	3hr05min
7	21.2	0.78	55	2.03	3hr25min
		0.74	52	1.85	3hr20min
	*18.0	1.56	41	0.75	5hr30min
		1.70	49	1.00	4hr10min

*Acclimated for 24 hours at 18°-19°C.

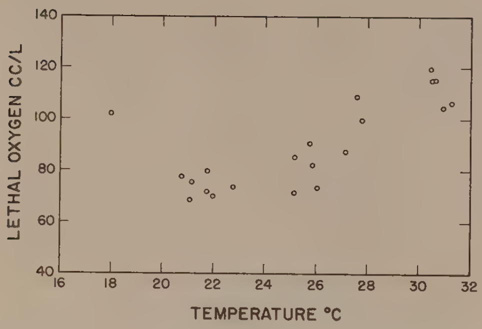

Figure 12.--Lethal values of oxygen at different temperatures. Points represent the average of two trials at each temperature.

Discussion

Lethal values of oxygen for individual iao ranged from 0.50 to 1.58 cc./l. (combined summer and winter data). There was less variability in the winter data, as evidenced by the smaller standard deviation (0.18 cc./l. as compared with 0.22 cc./l. for the summer data). Some of the variability in any one season's experiments was probably caused by differences in the temperature of the experiments and possibly in the size of the fish used, although the influence of the latter is doubtful. The range of temperatures in the summer experiments was greater than in the winter tests, which could serve to increase the variability of the summer data. Furthermore, in certain instances where fish of exactly the same weight were used, the lethal values of oxygen were identical, but the duration of the respective experiments differed markedly, indicating a marked difference in metabolic rate between the fishes concerned.

Comparing the results on nehu with those of Suehiro (1951), who also worked with individual fish, it was apparent that the variation in his data was greater than that found in the present paper. Standard deviations calculated by the author from Suehiro's data were 0.54 for sardines and 0.44 for anchovies, as compared with 0.35 for the nehu. It is noteworthy that the mean lethal value of oxygen for nehu (2.02 cc./l.) agrees quite well with the mean values found by Suehiro for Japanese bait fishes (2.04 cc./l. for sardines and 1.80 cc./l. for anchovies).

Experiments using many fish gave a lower average lethal value of oxygen than tests on individuals although the range was about the same. The lethal values fell, for the most part, within the range from 0.55-0.85 cc./l. The reason for the lower average value is obscure, but the fish certainly appeared more quiescent when tested in groups rather than individually. Most species of trout appear, like the iao, to have a relatively narrow asphyxial range of oxygen concentrations (Gardner and King 1922, King 1943). Wilding's (1939) curves for three species of freshwater fish (yellow perch, steel-colored shiner, and blunt-nosed minnow) are similar in shape to the one for iao (fig. 10), but the total range in lethal values of oxygen is much greater in his case. It is noteworthy that Wilding withdrew oxygen samples when one or more of the fish showed symptoms of asphyxiation, as evidenced by loss of balance, irregular motion, etc. Complete asphyxiation is perhaps a better criterion to use in controlled laboratory experiments. Wells (1913), for example, states that the "turning-over time" for fish varies considerably within a species, some fish maintaining their equilibrium up to the point of complete asphyxiation. Observations by the writer also indicate a highly variable physical response by iao to lack of oxygen. Comparison with the results of other workers must, of course, be made with caution since the techniques employed are far from standardized. Furthermore, much of the material reported in the literature pertains to field observations on behavior of fish at low oxygen concentrations rather than laboratory experiments.

With the data available, no pronounced relationship between the size of the fish and its resistance to lack of oxygen could be demonstrated. This is somewhat contrary to the results of Keys (1931), who found that larger Fundulus were more resistant to asphyxiation and states that this was due to the smaller oxygen demand per unit weight of the larger fish. Moore (1942), working in the field with several freshwater species, also observed that larger fishes survived critical oxygen concentrations longer than smaller individuals of the same species. On the other hand, Wells (1913) found just the opposite for trout, small fish showing a greater resistance per unit weight than large ones. Suehiro's (1951) data on individual fish present a better comparison with the results reported in this paper. His weights, for both sardines and anchovies, when plotted against the lethal value of oxygen, are even more randomly scattered. It would seem, for iao at any rate, that regardless of a probable higher metabolic rate in the smaller fish, they are not markedly hindered in their ability to extract oxygen from water low in oxygen content.

A small, but nonetheless statistically significant, difference was found between the mean summer lethal value of oxygen (1.0 cc./l., average temperature 25.6°C.) and the mean winter value (0.96 cc./l., average temperature 21.9°C.). This difference is of about the expected magnitude according to the relationship of temperature to the lethal value of oxygen (fig. 12). In the absence of the appropriate data, however, it is difficult to determine the possible influence of purely seasonal differences in the behavior of the fish.

A few investigators (Gardner and King 1922; Moore 1942; Fry et al. 1947; Graham 1949) have studied the effects of temperature on lethal values of oxygen in fish and found, as in iao, that the lethal level of oxygen increases as the temperature increases. The curve of temperature versus lethal values of oxygen (fig. 12) shows a somewhat steeper rise from 26° to 31°C., roughly corresponding to the pattern shown in the relationship of metabolic rate to temperature (fig. 4). Thus, with a greatly increased metabolic rate at the higher temperatures, the fish is less able to cope with low values of dissolved oxygen. This observation may be of some importance to the live-bait fishery. As mentioned earlier, the fishery is conducted primarily in the summer months, when temperatures often rise above 26°C., particularly in calm anchorages. At the higher temperatures, even a small increase in temperature may bring about a marked decrease in the resistance of the fish to oxygen deficiency.

The lethal values of oxygen reported here from laboratory experiments should be checked by more extensive measurements taken directly from the live-wells of the fishing boats. Such tests might possibly give lethal values intermediate between the average for iao (about 1.0 cc./l.) and that for nehu (about 2.0 cc./l.), since many bait loads are "mixed", containing both nehu and iao.

SUMMARY AND CONCLUSIONS

1. Confinement of tuna baitfish in small live-wells pointed to the desirability of a study of the oxygen requirements of the fish. Experiments were designed to determine lethal levels of oxygen and the rate of oxygen consumption under various conditions. In the oxygen consumption experiments special emphasis was laid on the effects of crowding, flow-rates, and the oxygen concentration of the water.

2. A flowing-water method was used to measure oxygen consumption, dissolved oxygen being determined by the unmodified Winkler procedure. For tests of lethal values of oxygen, where the fish were asphyxiated in sealed jars, the permanganate modification of Winkler's technique was employed.

3. The results are summarized below:

   a. From serial observations, it was evident that oxygen consumption in the iao showed considerable hour-to-hour fluctuation even when there were no outward signs of increased or decreased activity on the part of the fish. No rhythmic cycle in metabolic rate could be demonstrated, at least during the first 24 hours in the container.

   b. Oxygen consumption increased with increase in flow-rate, the effect being perhaps more pronounced in the summer months. In addition, oxygen consumption per unit weight was significantly lower in the tests with large numbers of fish. Possible reasons for the latter finding were discussed.

   c. The "critical oxygen level", i.e., the point at which the rate of oxygen consumption became dependent upon the oxygen concentration of the water, could not be precisely delimited but lay somewhere between 1.5 and 2.5 cc./l. Below this level, both breathing rate and oxygen consumption steadily decreased.

d. Individual iao showed marked differences in resistance to oxygen deficiency. Lethal values of oxygen ranged from 0.50 to 1.58 cc./l., the mean of the summer tests being 1.10 cc./l. and of the winter tests, 0.96 cc./l. A similar range in lethal values was obtained from the experiments where several fish were asphyxiated at once, but almost all the values fell within the narrow interval from 0.55 to 0.85 cc./l., depressing the average to 0.69 cc./l.

e. Over the temperature interval from 19° to 29°C., the rate of oxygen consumption increased slowly at first and then more rapidly at the higher temperatures. Lethal values of oxygen, measured over the same range, also showed a greater increase between 26° and 31°C.

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The Problem of the Smooth Muscle.

P. B. van WEEL

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Estratto dalle « Pubbl. Staz. Zool. Napoli » - Vol. XXVII (pagg. 10-16)

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The Problem of the Smooth Muscle.

(con 5 figure nel testo)

(ricevuto il 8-I-1955)

For nearly half a century the smooth muscle has been a « mysterious » organ. Its peculiar properties: the maintenance of its tonus without the use of an appreciable quantity of energy, its plastic yielding to a deforming force without loss of tonus, its slow tonic contraction, etc., are problems even now not fully understood. It was particularly JORDAN and his pupils, who, in years of tedious research, tried to unravel these « mysteries ». His latest, but by no means final conception (during the last years of his life he tended already to depart from these views, being aware of the fact that his conception did not satisfactorily explain all phenomena) was presented in his theory of the snow plough-effect. According to this theory the smooth muscle is built by submicroscopic elastic and contractile micellae, imbedded in a viscous intermicellar fluid. Stretching the muscle means displacement of the micellae through the viscous fluid, leading to an increase in resistance, caused by the viscous fluid being « piled up » in front of the micellae (like snow in front of a snow plough). His experiments, often repeated and improved by his pupils, seemed at first to confirm this theory. However, the snow plough-effect as such is not sufficient to explain the maintenance of the tonus of a muscle at rest (or « constant length »), because even the weight of the muscle itself would cause its deformation, if there were no other factors present to counteract the « plastic flow ». This was demonstrated for example by POSTMA (1953), who was able to show that the lengthening reaction (the so-called BINGHAM curve) of smooth muscles of hollow organs is characteristic for the smooth muscle of the foot of some gasteropods only (*Helix* and *Cepaea*), but that it does not appear in *Arion*, *Limax*, *Limnea* and *Planorbis*, whereas *Milax* seems to take an intermediate position. According to him the lengthening reaction, when it is present, is caused by lengthening and tension reflexes, not particularly by the snow plough-effect. (The effect of the central nervous system, particularly of the pedal ganglia, on the tonus of the foot has been pointed out repeatedly by JORDAN himself). In 1943 POSTMA proposed the hypothesis, that in smooth muscle the resistance against deformation is based on the presence of a « tonus » or t-substance, which determines the structure of the muscle colloids. The t-substance would be subject to an enzymatic break-down (the so-called « peripheric consumption of the tonus »). Next to the t-substance there would be an inhibitor, which would be able to « crowd out » the t-substance. By doing so, it would decrease the tonus quickly (the enzymatic break-down would be a slow process). In the resting muscle there would exist a balance between (a) production of t-substance (and consequently an increase in tonus), (b) its enzymatic break-down and (c) the quantity of inhibitor present. A light stretching weight would cause an increase in the production of the t-substance (increase of the tonus until the carrying tonus level is reached), a heavy weight would induce an increased production of inhibitor (rapid loss of tonus). Production of these « humoral » substances would not cause an appreciable increase in the metabolism, since they are active in very small amounts. The nervous system (pedal, but also the cerebral ganglia) would have a marked effect in the interaction of these substances. POSTMA (1953) also pointed out, that JORDAN's distinction between relaxation and mollification in the smooth muscle (the existence of which is often denied) does exist, also in the striated muscle, where ATP would act as a « mollificator » in the absence of ATP-ase.

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*) Contribution No. 62, Hawaii Marine Laboratory.

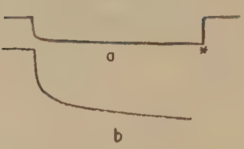
It must be kept in mind, that POSTMA's hypothesis, based on an intramuscular « humoral » activity, will remain a hypothesis, so long as the « hormones » have not been isolated. His thought-provoking ideas have led to the experiments on smooth muscles of holothurians, reported in this paper. JORDAN (1914, 1916) had pointed out already, that in these animals there seem to exist two different systems of smooth musculature: (a) the « normal » smooth muscles and (b) the cutis fibers. The latter have a predominant tonus function (slow contraction is only possible when such injuring stimuli like stabbing, etc., are applied), whereas the former ones contract normally on stimulation. In order to determine the activity of the nervous system (both central and « diffuse »), all experiments performed on muscle and cutis of untreated holothurians were repeated with those of holothurians poisoned with curare. DU BUY (1936) had demonstrated already, that curare (a) does not affect local contractions, (b) does not change the plastic properties of the muscle, but (c) does block the nervous impulses effectively in these animals. The effect of Mg^{++}-ions on the muscles was also studied. For this purpose the muscles were immersed in sea water, containing 1.2% $MgCl_2$, for 2 hours previously to the experiments and during the experiments they were kept in the same solution. Most of the experiments were carried out on muscles and cutis strips of *Holothuria atra* (JAGER) and *H. monocaria* (LESSON), fewer on *H. edulis* (LESSON), *Stichopus tropicalis* (FISCHER), *Opheodesoma spectabilis* (FISHER) and *Actinopyga mauritiana* (QUOY and GAIMARD). Stretching was recorded isotonically with POSTMA's ordinate lever (1935) as modified by KIPP (1939). The muscles were always kept submerged in sea water. HARVARD's muscle warmer proved to be ideal for this purpose

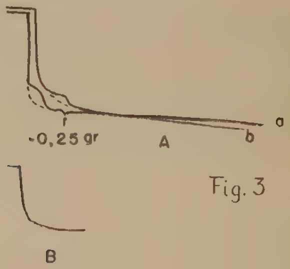
A. The smooth muscle.

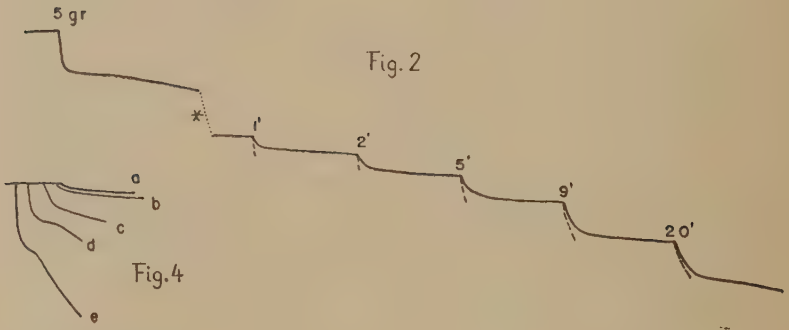
Stretching the muscle with a small load (2-2.5 grs.) as a rule led to the well known BINGHAM curve. An exception was often found in the muscle of *Opheodesoma*: When loaded with a heavier weight (5 grs.) it very often shows a steep « free fall », whereupon the curve suddenly takes a horizontal course (fig. 1 a). Release of the load causes in this case the muscle to reassume its original length equally suddenly. Apparently the muscle acts with this load as an elastic system, whereas with a load of 1.25 grs. the BINGHAM curve is invariably obtained (fig. 1 b). The recovery (after release of the load) is in all cases comparatively large and depends also on the temperature: with a muscle of *Opheodesoma*, stretched with 1.5 grs. until the muscle increased in length for 10-13.5 mm., the recovery at 19°C was 22%, at 24.2°C: 30%, at 25.5°C: 40%. A complete recovery was never obtained during a period of 3 hours, after which the experiment was terminated.

JORDAN's snow plough-effect could be demonstrated easily (fig. 2). The same was the case with JORDAN's paradoxon of the decrescent $MgCl_2$, acting on the intact animal, turns it completely limp in 5.5 hours. The same can be observed in an isolated muscle. Weak stimulation causes a strong contraction. Stretching such muscles results in a very long free fall and a slower, more gradually curving out into a « horizontal stretch », which is, however, comparatively steep. Since Mg^{++}-ions do not only exert an effect on the nervous system, but apparently also on the muscle itself (ASHKENAZ 1938, MAASKE & GIBSON 1939), stretching curves were also obtained from muscles poisoned with curare. Again the same type of curve was obtained, be it slightly less steep (fig. 3 B). The « steps » in both curves (fig. 3 A) are artificial, caused by the fact that the muscle stuck to the wall of muscle warmer for a short time. Even the paradoxon of the descrescent could be obtained in the $MgCl_2$ and the curare muscles (fig. 3 A). From these observations the conclusion can be drawn that, although the nervous system has undoubtedly a definite effect on the tonus of the muscle (increase of the tonus level), their mechanical properties are not changed when the nervous system is blocked and that Mg^{++}-ions seem to decrease the tonus level of the muscle itself.

Low temperatures increase the tonus of the muscle (fig. 4). There is no loss of tonus, caused by low temperatures acting on the intact animal. Even when







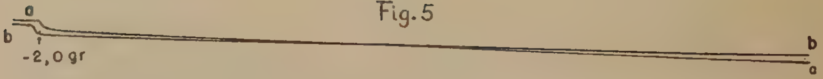


Fig. 1. - Longitudinal muscle of *Opheodesoma*. *a*: « elastic » stretching and recovery. At * the load (5 grs.) removed; *b*: visco-elastic stretching. Load: 1,25 grs.

Fig. 2. - Longitudinal muscle of *H. atra*. Snow plough-effect, recorded with a heart lever. * : center part of the normal stretching curve not copied. Time pauses in minutes.

Fig. 3. - Longitudinal muscle of *H. monocaria*, poisoned with curare. A: paradoxon of the decrescent. *b*: load of 0.50 grs.; *a*: load of 0.75 grs. B: stretching curve with a load of 0.75 grs.

Fig. 4. - Effect of the temperature on the slope of the stretching curve (longitudinal muscle of *H. monocaria*, load of 2.25 grs). *a*: 11°C; *b*: 14°C; *c*: 17°C; *d*: 20°C and *e*: 23°C.

Fig. 5. - Cutis muscle of *H. atra*. Paradoxon of the decrescent. *a*: load of 5 grs; *b*: load of 7 grs.

kept at 5°-6°C over night, holothurians appear rigid and hard and it takes quite a long time (40 minutes and longer), before they regain their normal tonus and motility at normal temperatures (22°C).

B. The cutis.

Piercing a cutis strip with a hook in order to fasten it to the apparatus, causes it to become very hard and it takes a considerable time before the normal tonus is reached again. In *Opheodesoma*, which has an extremely thin cutis, a mechanical damage to the cutis apparently causes an increase in tonus for a very long period: When a small hole is cut in the cutis of this holothurian, it is immediately closed by contraction of the sub-dermal muscles and kept closed by the increased tonus of the cutis, until the wound is healed. $MgCl_2$ has apparently no effect on the cutis, although it does have so on the muscles.

Stretching causes a short, perpendicular free fall, followed by a straight decline, which seems to continue « indefinitely ». The angle of the « horizontal » stretch, which depends on the weight of the load but which is certainly not in proportion to it (a heavy load causes only a slightly steeper « horizontal stretch » than a light load), does not seem to alter for at least 3 hours, after which the experiment was terminated and the cutis strip became stretched to 2x its original length. Neither $MgCl_2$, nor curare seem to have an effect on shape and slope of the stretching curves. The snow plough-effect is remarkable. Even the paradoxon of the decrescent can be demonstrated (fig. 5). However, since the cutis does not contract on electrical stimuli, it has to be pushed back manually to its original length (see JORDAN 1914), before the second curve can be recorded.

A very interesting observation, made twice on a longitudinal muscle of *H. monocaria* and once on a muscle of *Opheodesoma*, is the following one: the muscle, poisoned by curare, was stretched for a very long time with a weight of 2.5 grs. It increased its length during this period for about 300% (the second time for about 360 %), in the mean time became quite thin, when it suddenly snapped in the middle in the same way as a « thread » of plastic material which is pulled out snaps. In a normal muscle such an extreme stretching never occurs (the developing carrying tonus, probably of nervous origin, makes this impossible). This shows, that the carrying tonus is probably induced by the nervous system, whereas, when the latter is blocked, a carrying tonus does not develop and the muscle yields plastically until it snaps.

How do these observations fit in POSTMA's hypothesis? The experiments on the muscles of *Opheodesoma* do not agree with his conception, that a light weight increases the production of the t-substance and hence increases the tonus, whereas a heavy weight causes a loss of tonus by production of the inhibitor (since these muscles are very thin, a weight of 5 grs. is indeed a comparatively heavy one). What is more, the experiments showing the paradoxon of the decrement do not agree with this conception either: When stretching with a heavy load would cause a decrease in tonus, the curves would never cross, as they do. On the other hand the observations fit perfectly in JORDAN's picture of micellae imbedded in a viscous fluid, although admittedly this conception is certainly too simplified. Also the observations of the « snapping » muscle, when the nervous system is blocked, caused by overstretching with a very light weight. Apparently the intermuscular connective tissue in these muscles is too weak to resist even this weak but long lasting pull. However, the experiments also show that the nervous system, even in the isolated muscle strip, has a very important effect on the tonus of the muscle and that it probably must be regarded as the system responsible for maintaining the tonus of the smooth muscle. But the basic properties of the smooth muscle seem to be of a « plastic » nature and seem to be still basically different from those in striated muscles.

JORDAN's life program, now continued along a different track by his pupil POSTMA, found its start in Naples' Zoological Station, as so many other highly important projects did and do. To no small degree this is made possible by the capable assistance and friendly hospitality, for which « Naples » is justified famous and for the « younger generation » these are embodied in the former director, Dr. R. DOHRN and his staff. I deem myself extremely happy in considering myself one of the lucky people, who actually started his scientific life in these happy surroundings and who profited so very much by the hospitality displayed by Dr. R. DOHRN and his family.

Summary

The maintenance of tonus and the plasticity of smooth muscle are considered in the light of the theories of JORDAN and of POSTMA. In experiments on Holothurian muscle the author shows that the mechanical properties are largely uninfluenced by nervous block (curare and magnesium chloride) though the nervous influence is responsible for increased tonus. Plasticity effects recorded for *Opheodesoma* tend to support JORDAN's concept of the muscle rather than that of POSTMA.

Riassunto

Il mantenimento del tono e la plasticità del muscolo liscio sono considerati alla luce delle teorie di JORDAN e di POSTMA. Negli esperimenti su muscoli di Oloturia l'A. dimostra che le proprietà meccaniche sono largamente influenzate dal blocco nervoso (curaro e clorito di magnesio) benchè l'influenza nervosa sia responsabile dell'accrescimento di tono. Gli effetti di plasticità ricordati per *Opheodesoma* sembrano confortare la concezione del muscolo di JORDAN piuttosto che quella di POSTMA.

Zusammenfassung

Die Aufrechterhaltung des Tonus und die Plastizität der glatten Muskeln wird im Licht der Theorien JORDAN's und POSTMA's besprochen. An Hand von Experimenten mit Holothurien-Muskeln kann der Autor zeigen, dass die mechanischen Eigenschaften weitgehend durch nervöse Blockierung (Curare und Magnesiumchlorid) beeinflusst werden, wobei das Nervensystem für den erhöhten Tonus verantwortlich ist. Die bei *Opheodesoma* festgestellten Plastizitätseffekte scheinen JORDAN's Interpretation des Problems und nicht diejenige POSTMA's zu stützen.

Résumé

Le maintien du tonus et la plasticité des muscles lisses sont discutés sous l'aspect des théories de JORDAN et POSTMA. Grâce à des expériences exécutées sur les muscles d' Holothuries l'auteur peut démontrer, que les propriétés mécaniques sont en grande partie influencées par un blocage nerveux (curare et chloride de magnésium). L'influence nerveuse est responsable de l'augmentation du tonus. Les effets de plasticité observés chez l' *Opheodesoma* semblent confirmer plutôt la conception de JORDAN que celle de POSTMA.

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STETHOJULIS RENARDI, THE ADULT MALE OF THE LABRID FISH *STETHOJULIS STRIGIVENTER*.—In a collection of fishes from the Gilbert Islands, Oceania, are five specimens which I identified in the field as *Stethojulis renardi* (Bleeker, 1851) and five of *Stethojulis strigiventer* (Bennett, 1832). The specimens of *renardi* range from 72 to 75 mm. in standard length and were more colorful than the smaller individuals of *strigiventer* (52 to 69 mm.). The former had four dark-edged red lines on the head and body as shown in Bleeker's Atlas Ichthyologique (1862, vol. 1, pl. 43, fig. 2). The area between the two lowermost red lines was blue posterior to the eye, and the lower half of the body was whitish with traces of lengthwise narrow white lines. In the brown *strigiventer* (Bleeker, ibid, fig. 1) there are five or six narrow lengthwise white lines on the ventral half of the body. In both species there is a tiny black spot or pair of spots at the base of the caudal fin just above the last lateral-line scale. Specimens of *strigiventer* less than 64 mm. have a small black spot on the next to last dorsal ray near its base, and those smaller than 50 mm. display a similar spot on the next to last anal ray.

I was unable to distinguish the two species on any other basis than color. All of the meristic data (D IX, 11; A III, 11; P 14 or 15; lateral-line scales 27; gillrakers 24 to 26) are the same in both. In preservative, with the bright hues of *renardi* faded, several specimens were sorted with difficulty.

Sex determination revealed that all five specimens of *S. renardi* are males whereas the specimens of *strigiventer* represent both sexes. A series of the two species in the United States National Museum which were collected at Guam were examined. There were 18 specimens of *renardi* from 62 to 81 mm. in standard length, all of which were males. Forty-two specimens larger than 34 mm. (those less than 34 mm. could not be sexed with assurance) were labelled *strigiventer*; of these, 14 were females (63 to 68 mm. long) and the remainder consisted of 16 females and 12 males. No males with *strigiventer* coloration exceeded 62 mm. in standard length. Three male specimens, 61 to 62 mm. long, were intermediate in color pattern between typical *renardi* and *strigiventer*. I therefore conclude that *S. renardi* is the large adult male of *S. strigiventer*, and that the *renardi*-type color develops (at least at Guam) at a length of about 61 to 62 mm.

Maturity in the male seems to be reached before the *renardi* form is assumed, for specimens as small as 47 mm. have well-developed testes. The male apparently reaches a larger size than the female. The largest female specimen was 68 mm.; 10 males were longer than 70 mm.

Sexual dimorphism to the extent that the males and females bear different names is not unknown in the Labridae. Longley (in Longley and Hildebrand, 1941: 196) discussed a comparable situation in *Thalassoma bifasciatum* (Bloch), in which only the large male attains the "*bifasciatum*" color pattern. In another case, however, Günther (1909: 291, pl. 148) was in error in considering the form illustrated in figure C to be the female of *Thalassoma duperreyi* (Quoy and Gaimard) (fig. B). The former is another species, *T. ballieui* (Vaillant and Sauvage), with the color inaccurately depicted.

Sexual dichromatism is far from being a widespread phenomenon in the wrasses; nevertheless more examples probably remain to be elucidated.

This paper is contribution No. 63, Hawaii Marine Laboratory in cooperation with the Department of Zoology and Entomology.—JOHN E. RANDALL, *Department of Zoology and Entomology, University of Hawaii, Honolulu, T. H.*

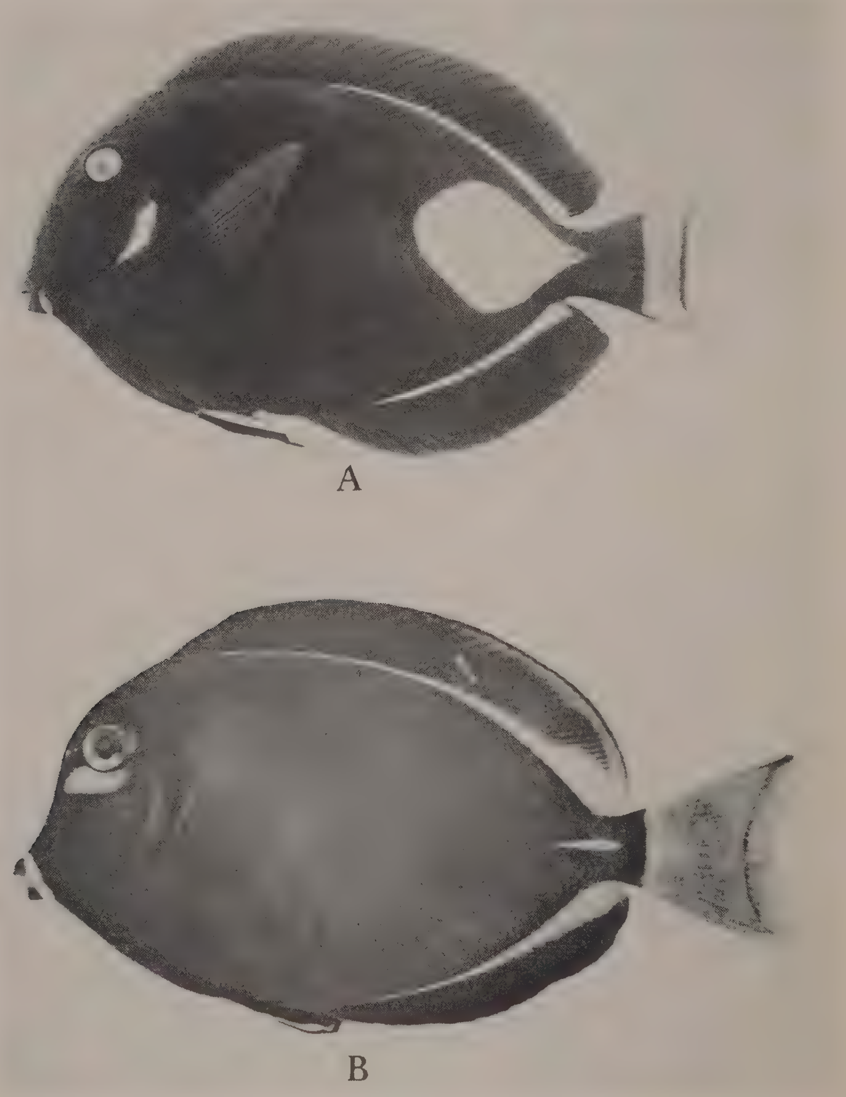

PLATE I

A—*Acanthurus achilles.* Reproduced from a 35-mm. Kodachrome transparency of a 170-mm. specimen from the Hawaiian Islands.

B—*Acanthurus glaucopareius.* Reproduced from a 35-mm. Kodachrome transparency of a 112-mm. specimen from the Gilbert Islands.

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Acanthurus rackliffei, a Possible Hybrid Surgeon Fish (*A. achilles* × *A. glaucopareius*) from the Phoenix Islands

John E. Randall

THE published records of naturally occurring hybrids of freshwater fishes are very numerous; those of marine fishes are exceptionally few in number. In an unpublished review of hybridization in New World fishes, Robert Rush Miller advises me that only 5 marine hybrids have been reported (1954) in contrast to 129 freshwater crosses. Only one additional instance of hybridization in marine fishes has come to his attention since this list was prepared. The overwhelming majority of freshwater hybrids is reflected not only from our greater knowledge of American freshwater fishes and greater opportunity for sampling populations of freshwater habitats but probably also from an actual lower percentage of hybrids in the sea. Undoubtedly conditions are more favorable, in general, for hybridization of fishes in the freshwater environment than in the marine.[1]

Acanthurus rackliffei (Schultz, 1943: 157, 163, fig. 13) is known from three specimens, each collected in a different locality (a pool on the reef, the outer edge of the reef, and the channel connecting the ocean to the lagoon) at Hull Island, an atoll in the Phoenix Islands, Oceania. Admittedly three specimens are too few on which to base evidence of hybridization, but the intermediacy of these between *Acanthurus achilles* Shaw and *Acanthurus glaucopareius* Cuvier is such that their hybrid nature appears probable. Also, in view of the above-mentioned paucity of records of hybrid marine fishes, even suspected cases are well worth documenting.

I know of no reference to hybrid surgeon fishes. The marine hybrid closest from a phylogenetic standpoint is an example in the Chaetodontidae from Tortugas, Florida, cited by Longley (in Longley and Hildebrand, 1941: 154). He concluded that *Holocanthus townsendi* (Nichols and Mowbray) was probably a cross between *H. ciliaris* and *H. isabelita*.

Acanthurus achilles (Pl. I A) is a strikingly colored fish, dark purplish black in life with a large elliptical bright orange spot posteriorly on the body. At the rear this spot has a characteristic sharp, folding spine. The spot has been cited as an example of warning coloration in fishes. Similar, but apparently independently acquired, bright color around caudal spines of *Acanthurus monroviae* Steindachner, *Naso lituratus* (Schneider) and *Naso unicornis* (Forskål) supports this contention. *A. achilles* is abundant in the oceanic islands of the tropical Pacific. Günther (1861: 340) recorded it from China. It is not known from the East Indies, and there is but one questioned reference to it from the Philippines (Elera, 1895: 532). Herre (1927: 414, pl. 2, fig. 1) included it in his report on Philippine surgeon fishes only on his belief that it occurred in the Philippine Islands. His specimen was from Guam.

Acanthurus glaucopareius (= *aliala* Lesson) (Fig. 1 C) is also dark but lacks the orange spot. This species has an oval white area beneath the eye and bright yellow coloration at the base of the dorsal and anal fins. It is an even more wide-ranging species, known from the entire tropical Pacific, and is one of the few surgeon fishes to have crossed the eastern Pacific barrier (Ekman, 1935: 105), being recorded from the Galápagos Islands, Cocos Island, Clipperton Island, and the Revillagigedo Islands. It does not appear to be present in the Indian Ocean except for Christmas and Cocos-Keeling Islands.

These two species, along with *Acanthurus leucosternon* Bennett, from the East Indies and tropical Indian Ocean, are closely related. They share a number of characteristics that separate them from other species of *Acanthurus*. They are high-bodied, and the profile of the head is steep and convex; the mouth is somewhat produced and very small (its width from rictus to rictus is contained about 5 to 6 times in the length of the head, as opposed to 3.2 to 4.8 for other species); the teeth are large, few in number (never over 12 in either jaw), and different in shape from other surgeon fish (see Aoyagi, 1943, pl. 6, fig. 19 for drawing of teeth of *glaucopareius*); dorsal and anal fin-ray counts are high; there is a white line on the chin adjacent to the lower lip; the size of *achilles* and *glaucopareius* (that of *leucosternon* not seen) at transformation from the acronurus or late postlarval stage to the juvenile form is very large, about 55 to 60 mm. in standard length. The largest of numerous examples at transformation of all of the other species of *Acanthurus* that I have examined is 38 mm., and some are as small as 18 mm. The sum total of these characters would be of sufficient magnitude to warrant consideration of these three species as a subgenus, were it not for *Acanthurus pyroferus* Kittlitz (= *celebicus* Bleeker) (= *leucosternon* Fowler and Bean, Aoyagi, and Schultz and Woods), which serves as a connecting link to more typical forms of *Acanthurus*.

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[1] After this paper was in press, a comprehensive article on the natural hybridization of fishes appeared (Hubbs, 1955). The reader is referred to that work for a more detailed discussion of hybridization in marine fishes.

The similarity of *achilles* and *glaucopareius* is not restricted to morphology, but carries over to habitat and to their herbivorous food habits. On the outer reef, windward side, of Onotoa Atoll in the Gilbert Islands, *achilles* was most characteristic of surge channels, not the surf zone where *Acanthurus guttatus* is the index form, but the outer, somewhat less turbulent part. *A. glaucopareius*, though seen in surge channels and elsewhere in the atoll, was most abundant on the inshore part of the coralliferous terrace. These two regions of the reef are not sharply demarcated from one another, and there is a broad overlap of the zones occupied by the two species; they were frequently observed swimming side by side. Harry (1953: 150) stated that *glaucopareius* (his *Acanthurus sp. one*) was often in association with *Acanthurus achilles* at Raroia Atoll, Tuamotu Archipelago. The stomach contents of 10 specimens of *achilles* and 12 of *glaucopareius* from Hull and Enderbury Islands in the Phoenix group were examined and found to be essentially the same in both species. Most of the algae was fine and filamentous, and very little sedimentary material was present. No single alga predominated, although there were more reds in general, such as *Alsidium* sp., *Gelidium* sp., and *Lophosiphonia* sp. than greens, browns, or bluegreens. More *Caulerpa serrulata*, a green alga common on the outer part of the reef flat, was found in *achilles* stomachs, probably reflecting the greater tendency on the part of this species to enter shallow water. (Algal determinations by M. Doty and M. Bell, University of Hawaii.)

Nothing is known of the breeding habits of either species. The gonads of 36 adult specimens of *achilles* and 27 of *glaucopareius*, collected from May to September in the Phoenix,

TABLE I

COMPARISON OF COLOR AND MORPHOLOGY OF *Acanthurus achilles*, *Acanthurus glaucopareius*, AND HYBRID

Character	*achilles*	*achilles* × *glaucopareius*	*glaucopareius*
Shape of caudal fin	Strongly lunate	Moderately lunate	Emarginate
Dark submarginal line in caudal fin	Present and prominent	Present	Faint and narrow
Demarcation of dark body color and pale color of caudal fin	Located at base of caudal fin	Located ⅕ caudal length distal to base of caudal fin	Located ⅖ caudal length distal to base of caudal fin
Pale area around and in front of caudal spine of adults	Large	Small	Absent
Pale area at base of posterior dorsal and anal fin rays	Narrow, about ¼ length of last few rays	Moderately broad, about ½ length of last few rays	Broad, about ⅞ length of last few rays
Color and width of middle part of opercular membrane	White and broad	Dark and narrow	Dark and narrow
Pale spot under eye	Absent	Faint, maximum height ½ eye diameter	Large and conspicuous, maximum height ⅔ eye diameter
Pale mark on chin	Ends at rictus	Ends at rictus	Extends above rictus

TABLE II

FIN-RAY COUNTS OF *Acanthurus achilles*, *Acanthurus glaucopareius*, AND HYBRID

Species and locality	Dorsal soft rays						Anal soft rays			
	28	29	30	31	32	33	26	27	28	29
achilles										
Phoenix Islands....	..	1	3	5	2	..	..	3	6	2
Oceania.....	..	7	28	53	32	2	3	25	56	38
achilles × *glaucopareius*	..	1	1	1	..	..	..	2	1	..
glaucopareius										
Phoenix Islands....	1	3	6	2	..	..	3	9	..	..
East Indies, Oceania, and Galapagos Islands......	8	30	31	6	..	..	19	48	8	..

Gilbert, and Marshall Islands, were found to be in all stages of development and no trend could be perceived over this period. Occasional specimens of both species, collected at the same time, had comparably developed gonads. Study of a much larger number of adult *Acanthurus triostegus* from Pacific islands of the lower latitudes revealed ripe fish throughout the year. It is believed that there is no definite spawning season for these fishes in these regions. This might be expected from the very slight annual variation in water temperature.

A. achilles and *A. glaucopareius* may be separated primarily by caudal-fin shape, a slight difference in number of dorsal and anal fin rays, and by color (Tables I–II). It will be noted that the postulated hybrid either shares color characters of *achilles* or *glaucopareius* or is intermediate. Fig. 1 shows the posterior parts of specimens of about equal size of all three forms from Hull Island. The illustration of the hybrid is drawn from the paratype of *rackliffei* in the Museum of Comparative Zoology, Harvard College. The holotype and a small paratype are in the United States National Museum. There appears to be a progressive development of the pale area around the caudal spine in the three specimens of *rackliffei*. It is absent in the 68-mm. paratype, narrowly developed in the 150-mm. holotype, and obvious in the 161-mm. paratype, as figured. In *achilles* there is a similar enlargement of the pale area around the spine with

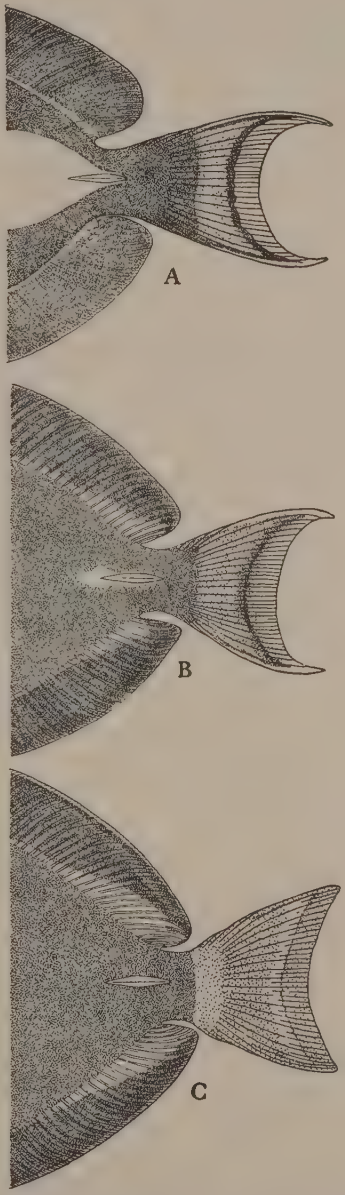

Fig. 1. Caudal regions of: A—*Acanthurus achilles*, B—*Acanthurus rackliffei* (*achilles* × *glaucopareius*), and C—*Acanthurus glaucopareius*, all from Hull Island. Standard length 158 to 161 mm. Drawing by L. B. Isham, United States National Museum.

age, although it takes place over a much shorter range in standard length and is first visible at a smaller size (about 65 to 70 mm.). The absence of the orange spot in the young led Günther (1873: 114, pl. 77, fig. B) to err in describing a juvenile *achilles* as a new species, *Acanthurus aterrimus*. Schultz (1943: 162) should be credited as the first to recognize the identity of the two.

Although I have indicated in Table I that the pale chin mark does not extend above the rictus in the hybrid, it does so very inconspicuously in the 161-mm. specimen.

A definite difference can be seen between the counts of the soft rays of the dorsal and anal fins of *achilles* and *glaucopareius*, but an overlapping exists. The counts for the three hybrids are about as intermediate as they could be, but it is apparent that many more specimens are needed to indicate where the modes of fin-ray counts lie.

Gillraker counts are not useful in effecting a separation of *achilles* and *glaucopareius*, for they vary from 16 to 20 in both species. The holotype of *rackliffei* has 18 anterior and 19 posterior rakers on the first gill arch.

On two extremes of its range, *Acanthurus glaucopareius* has color phases which co-exist with the normal. Schmidt (1930: 102, pl. 6, fig. 3) described one as a subspecies (*Hepatus aliala japonicus*) from the Riu Kiu Islands. The most conspicuous feature is the white area beneath the eye. Instead of being restricted to the region immediately below the eye, it consists of a broad band that runs from the eye to the mouth. Aoyagi (1943: 210) reported on specimens from the Riu Kius that presented a series of color variants from *glaucopareius* proper to the *japonicus* form. Marshall (1950: 194) and Palmer (1950: 202) recorded a color form from Cocos-Keeling Islands and Christmas Island, respectively, which differs principally from the usual type in lacking a sharp demarcation between the dark body color and the pale caudal fin; instead, the two colors gradually merge over the proximal third of the fin. In addition the ground color of the dorsal and anal fins is a good deal lighter than that of normally colored specimens. Apart from color, no significant distinction could be made by either author. Were it not for the decidedly more lunate caudal fin, possible difference in fin-ray counts, and the similarity to *achilles*, one might consider *rackliffei* as another color phase of *glaucopareius*.

The possibility that *rackliffei* might be a valid species, fortuitously intermediate between *achilles* and *glaucopareius* cannot be discounted; however the latter two are common and *rackliffei* is rare—just as one would expect a marine hybrid to be (Schultz and Smith, 1936: 203). Also *achilles* and *glaucopareius* are so much alike that one might predict, *a priori*, that they would interbreed. Randall (MS) has succeeded in artificially fertilizing the eggs of *Acanthurus triostegus* from the Hawaiian Islands (although the larvae failed to develop past the sixth day). It might be possible to test the interfertility of *achilles* and *glaucopareius* in a similar way. Unfortunately this is not practicable in Hawaii, where *glaucopareius* is exceedingly rare. In the rest of Oceania *glaucopareius* is more abundant, and such an experiment could more readily be carried out.

The discovery of *rackliffei* in localities where either *achilles* or *glaucopareius* does not occur would be justification for rejecting the hypothesis of hybridization. *A. achilles* is recorded among the surgeon fishes of Wake Island (Fowler and Ball, 1925: 18; Fowler, 1940: 781), but *glaucopareius* is not. A week of extensive collecting and underwater observation at Wake Island by William A. Gosline and myself yielded no specimens of *glaucopareius*; however, *achilles* was extremely common. At Marcus Island Bryan and Herre (1903: 134) listed *achilles* but not *glaucopareius*. It is possible that the latter species is not present at these two outposts of Oceania. *A. achilles* appears to be absent from the following areas where *glaucopareius* is known to occur: Christmas Island and Cocos-Keeling Islands in the Indian Ocean, East Indies, Philippine Islands, Riu Kiu Islands, and islands of the tropical eastern Pacific. Admittedly the absence of a species from an area where it could logically occur is difficult to demonstrate. It was many years before *glaucopareius* turned up among the large fish collections made in the Hawaiian Islands.

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The Osteology and Relationships of Certain Gobioid Fishes, with Particular Reference to the Genera *Kraemeria* and *Microdesmus*[1]

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The Osteology and Relationships of Certain Gobioid Fishes, with Particular Reference to the Genera *Kraemeria* and *Microdesmus*[1]

WILLIAM A. GOSLINE[2]

INTRODUCTION

AMONG TROPICAL MARINE PERCIFORM FISHES there is a group of elongate, presumably burrowing forms of small to medium size that superficially resemble one another. Many of these, after varied systematic placement, have come to rest, somewhat uneasily, in the catch-all percoid family Trichonotidae (cf. Schultz, 1943: 261). An investigation of the osteology of one of these genera, *Kraemeria*, showed it to be a gobioid. Comparison with Smith's (1951) account of *Paragobioides copleyi* indicated that it, too, was a gobioid. Smith erected for the single genus *Paragobioides* the family Paragobioididae, which, however, he places near the percoid families Ammodytidae and Trichonotidae. Dr. George Myers called to my attention several years ago the resemblance between *P. copleyi* and the supposedly blennioid family Microdesmidae. Dr. L. P. Schultz has been kind enough to turn over to me two paratypes of *Microdesmus multiradiatus* for dissection. These, too, prove to be members of the perciform suborder Gobioidei.

The main purpose of the present paper is to place the genera *Kraemeria* and *Microdesmus* securely among the gobioid fishes. This has not been difficult, for osteologically the gobioids exhibit many distinguishing characters. A glance at the branchiostegal ray structure, the suspensorium, or even the caudal skeleton would seem sufficient to determine whether or not a fish is a member of the suborder Gobioidei. Indeed, the gobioids have often been treated as a separate order from the Perciformes, e.g., by Jordan (1923), Regan (1936), Smith (1949), and Koumans (in Weber and de Beaufort, 1953). On the other hand Berg (1940), Schultz (1948), and others consider the gobioids as a suborder of the Perciformes. I have no strong personal preference on the matter and assign the gobioids a subordinal status in this paper principally as a matter of conservatism.

Having brought *Microdesmus* and *Kraemeria* into the Gobioidei, the question arises as to the status of these two genera within the suborder. To aid in determining these points, several gobioids of the most divergent types available have been skeletonized. As there appears to have been very little comparative osteological work done on the gobioid fishes, these skeletons are reported on in some detail. The species skeletonized are as follows:

Microdesmus multiradiatus, Panama, formerly U.S.N.M. 85766
Kraemeria samoensis, Marshall Islands
Eleotris sandwicensis, Hawaiian Islands
Ptereleotris microlepis, Marshall Islands
Eviota epiphanes, Hawaiian Islands
Gobiodon rivulatus, Marshall Islands
Kelloggella oligolepis, Hawaiian Islands
Awaous stamineus, Hawaiian Islands

The classification of these species, except for *Microdesmus* which has always been considered a blennioid, according to Koumans (1931), apparently would be as follows:

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- Order Gobioidea
  - Family Eleotridae
    - *Eleotris sandwicensis*
    - *Ptereleotris microlepis*
    - *Eviota epiphanes*
  - Family Gobiidae
    - Subfamily Gobiodontinae
      - *Gobiodon rivulatus*
    - Subfamily Gobiinae
      - *Awaous stamineus*
      - *Kelloggella oligolepis*
  - Family Taenioididae
    - Subfamily Taenioininae
      - *Paragobioides copleyi*
  - Family Psammichthyidae [=Kraemeriidae]
      - *Kraemeria samoensis*

The osteology of these species might be more assimilable if the external appearance of each could be illustrated. However, this is not feasible. The best that can be done in this regard is to provide citations to existing figures of these species. These are: *Kraemeria samoensis*, (called *Vitreola sagitta*), Jordan and Seale, 1906, pl. 37, fig. 1; *Microdesmus multiradiatus*, Meek and Hildebrand, 1928, pl. 98, fig. 3; *Eleotris sandwicensis*, Jordan and Evermann, 1905, fig. 210 on p. 480; *Ptereleotris microlepis*, Koumans (in Weber and de Beaufort), 1953, fig. 91 on p. 367; *Eviota epiphanes*, Jordan and Evermann, 1905, fig. 211 on p. 482; *Gobiodon rivulatus*, Günther, 1877, pl. 109, figs. F and G; *Awaous stamineus* (the closely related, if not identical species *Gobius crassilabris* is illustrated by Günther, 1877, pl. 108, fig. B), Valenciennes, 1842, pl. 5, fig. 5; and *Kelloggella oligolepis*, Jordan and Evermann, 1905, fig. 215 on p. 488.

I wish to thank Dr. L. P. Schultz of the U. S. National Museum for turning over to me the specimens of *Microdesmus*, and Dr. D. W. Strasburg of Duke University for providing the Marshallese material from which the specimens of *Kraemeria*, *Gobiodon*, and *Ptereleotris* were drawn.

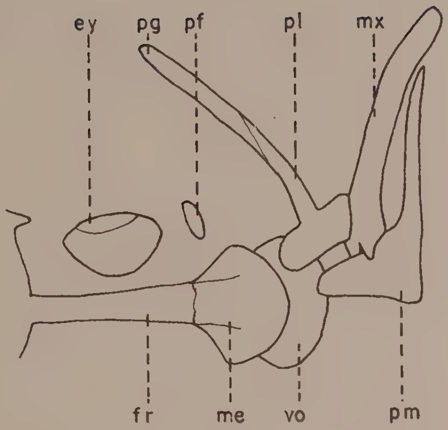

FIG. 1. Anterior portion of head skeleton (plus eye) of *Kraemeria*, from above. EY, eye; FR, frontals (the suture between the frontals is not visible in the interorbital region); ME, mesethmoid; MX, maxillary; PF, prefrontal; PG, pterygoid; PL, palatine; PM, premaxillary; VO, vomer.

COMPARATIVE OSTEOLOGY

Jaws

The jaw structure of the gobioids investigated seems to differ to only a minor degree from that of typical percoids. The strength of the jaws varies from fish to fish: in *Gobiodon* the jaws are short and heavy, in the other species longer and lighter. All the forms have a simple ascending pedicel to the premaxillary. In *Ptereleotris* this pedicel extends to above the middle of the eyes and is longer than the toothed portion of the premaxillary (undoubtedly indicating a protrusible upper jaw); in the other forms the pedicel is much shorter. In all except *Eleotris* the tooth-bearing portion of the premaxillary tapers to a more or less pointed tip laterally (Fig. 1). In *Eleotris*, the upper surface has a flange (similar to that shown by Gregory, 1933: 346 for *Eleotris pisonis*). The maxillary is usually a curved bar of approximately uniform cross-section behind its head (Fig. 1). In *Microdesmus* the maxillary is produced anteriorly from its articulation with the premaxillary pedicel as a strut that nearly meets its fellow from the other side in front of the premaxillaries. The lower jaw seems to show little variation in the gobioids examined.

Suspensorium

Regan (1911: 730, 731) uses the shape of the palatine as a character for differentiating between the Eleotridae and the Gobiidae. For the Eleotridae he states, "Palatine with an ascending stem articulating directly with a lateral ethmoid apophysis behind the origin of the maxillary process," and for the Gobiidae, "Palatine T-shaped with a posterior process for articulation with the lateral ethmoid." In this feature, *Eleotris sandwicensis* agrees well with Regan's first statement and with his figure of *E. marmorata* (1911: 730, fig. 1). *Awaous* (Fig. 2*c*) shows distinctly the gobiid palatine as described by Regan though it can hardly be called T-shaped. However, the palatines of *Ptereleotris* (Fig. 2*a*), *Eleotris*, and *Gobiodon* (Fig. 2*b*) appear to be more or less intermediate between the eleotrid and gobiid types. Indeed, one strongly suspects that Regan's palatine differentiation is not as distinctive as it appears. In *Microdesmus* (Fig. 2*d*) the palatine is a double-headed bone of peculiar shape which seems to be nearer that of *Awaous* than *Eleotris*. In *Kraemeria* (Fig. 1) the palatine does not seem to articulate directly with the skull at all, almost certainly not with the lateral ethmoid, a small bone lying loose in the flesh.

In *Eleotris* the palatopterygoid strut is more or less fused to the quadrate in typical percoid fashion (as shown in Regan, 1911: 730, fig. 1) although the mesopterygoid is reduced. In *Awaous* and *Gobiodon*, however, the palatopterygoid strut has become loosely and movably articulated with the quadrate and is thus a more or less independent unit from the rest of the suspensorium. In addition, the mesopterygoid has dropped out completely and the palatine extends backward to the very base of the strut. In all these features *Kraemeria* (Fig. 3*a*) and *Microdesmus* (Fig. 3*b*) resemble the gobiids rather than the eleotrids examined. There can be no doubt that the eleotrid type of palatopterygoid structure represents the least departure from the basic percoid suspensorium.

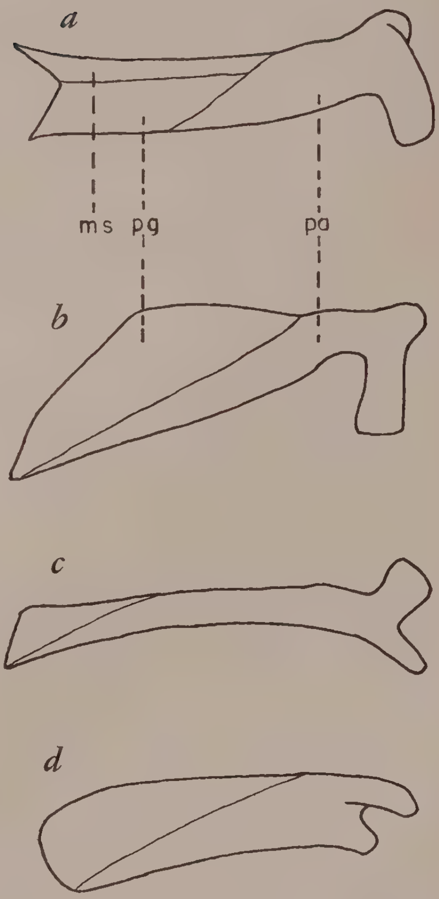

FIG. 2. Right palatopterygoid strut, from outside, of: *a*, *Ptereleotris*; *b*, *Gobiodon*; *c*, *Awaous*; *d*, *Microdesmus*. MS, mesopterygoid; PA, palatine; PG, pterygoid.

The most peculiar feature of the gobioid suspensorium is that the rear portion, between the articular and the cranium, instead of comprising the usual single hyomandibular-metapterygoid-quadrate strut, is composed of two struts with a large non-osseus area between them (Fig. 3). The anterior of these is made up centrally of the symplectic and metapterygoid and the posterior by the preopercle, which has become an integral part of the suspensorium rather than a superficial covering bone. Both supports run between the hyomandibular above and the quadrate below. The non-osseus space between the two struts is covered externally by heavy jaw musculature which so often gives the gobies a fat-cheeked appearance. (The necessity for space for this musculature may have been the causal agent in the development of the peculiar gobioid suspensorium.) I am unaware of a similar suspensorial structure in any other fishes. The closest approach to it may be that of the order Gobiesociformes. This structure seems to be common to all the gobioids. It is found in *Kraemeria* and *Microdesmus*, and is figured by Smith (1951: 522, fig. 1) for *Paragobioides copleyi*.

Opercular Series

The three opercular bones are present in all the gobioid fishes examined. I find nothing about them noteworthy in reference to the present study.

Gill Openings

The gill openings of all the species here investigated except *Kraemeria* are broadly attached to the isthmus. In *Microdesmus* the gill openings are restricted to a subvertical slit running partly ahead of and partly below the pectoral fins. In *Kraemeria* the gill openings extend far forward, and the gill covers are narrowly attached to the isthmus.

Branchial Arches

The glossohyal in gobioid fishes has recently been dealt with by Takagi (1950). He believes that the primitive gobioid glossohyal is a bar (as it is in most fishes) and that the broad fan-shaped and the forked form are specializations within the group.

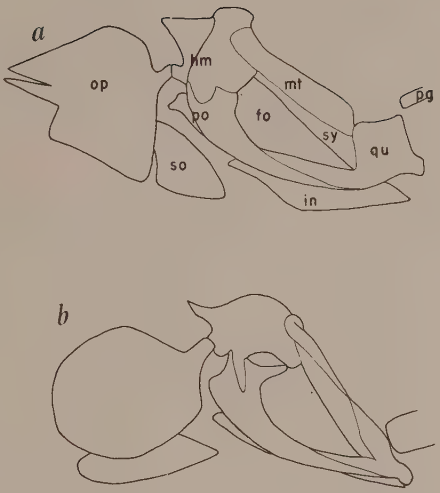

FIG. 3. Right suspensorium (except palatopterygoid strut) and opercular bones, from outside, of: *a*, *Kraemeria*; *b*, *Microdesmus*. FO, non-ossified area; HM, hyomandibular; IN, interopercle; MT, metapterygoid; OP. opercle; PG, pterygoid; PO, preopercle; QU, quadrate; SO, subopercle; SY, symplectic.

Among the fishes investigated here *Ptereleotris* has a very long, narrow glossohyal (similar to type A of Takagi's fig. 3), *Eleotris* a subtriangular bar (similar to type B), *Microdesmus* and *Kelloggella* a spatulate glossohyal (nearest to type C), *Gobiodon* a triangular glossohyal (of type C), *Kraemeria* a bar with a slight fork at the tip (near type F), and *Awaous* a broadly forked bar (of type V). Though these glossohyal types agree in general with Takagi's findings, my inability to read more than the summary of his article prevents my checking them in detail.

Another bone that seems to vary greatly in both extent and shape is the urohyal. Inasmuch as the significance of this variation is unknown it will not be described.

A highly diagnostic character for gobioid fishes would seem to be the ceratohyal structure and the branchiostegal ray configuration. The least specialized representation of these features would appear to be that of *Eleotris*.

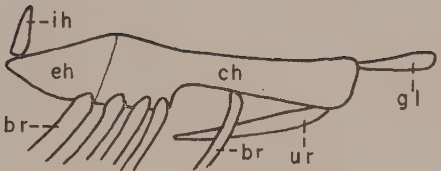

FIG. 4. Right hyoid arch, from outside, of *Kraemeria*. BR, branchiostegal rays; CH, ceratohyal; EH, epihyal; GL, glossohyal; IH, interhyal; UR, urohyal.

Here, as in the other gobies examined (e.g., *Kraemeria*, Fig. 4), the ceratohyal deepends rather abruptly about two-thirds of the way back. In front of this deepened section lie two branchiostegals; on the rear section are three more. The branchiostegals on the narrow and those on the deep section are separated by a considerable interspace. On the epihyal of *Eleotris* there is a sixth branchiostegal. In all of the other gobioids examined there is only one branchiostegal ray on the narrow portion of the ceratohyal, only five branchiostegals in all, and the interspaces between the first and the others is even wider than the interspace between the first pair and the last four in *Eleotris*. This one (or two) plus four sequence of branchiostegal rays not only seems to be characteristic of all the gobies, but to my knowledge is unique to the group. This same sequence is shown by Smith for *Paragobioides* (1951: 522, fig. 1).

So far as I can discern, the other most significant gill arch character within the gobioid fishes occurs in the lower pharyngeals. In *Awaous* the toothed upper surface of these two lower pharyngeals forms a single, coalesced, subtriangular plate. On the lower surface, however, the junction between the two sides shows as a median suture. In *Kelloggella* the two lower pharyngeals are contiguous but not fused. In the others examined, except *Kraemeria*, the lower pharyngeals are separate. In *Kraemeria* the two lower pharyngeals are fused with no sign of a suture either above or below. In *Microdesmus* the lower pharyngeals are small and widely separated.

The anterior gill arches of most of the genera investigated have weakly developed, pectinate gill rakers. *Gobiodon* differs in having a double row of spiny gill rakers on the gill arches.

Cranium

The degree of ossification of the skull of the gobioids investigated seems to bear little relationship to the adult size of the fish. For example the skulls of a 1 inch *Eviota* and an 8 inch *Awaous* are equally well developed. In two of the fishes, *Kelloggella* and *Ptereleotris*, the frontal and ethmoid regions are not well ossified, but this may be because juvenile specimens of the species were skeletonized rather than because the species were small. There is a membrane-covered fenestra over the otic bulla of *Kraemeria*.

The two exoccipital condyles are always well separated. In all the genera examined except *Kelloggella*, *Kraemeria*, and *Microdesmus*, the supraoccipital extends down to the exoccipitals thus separating the epiotics (Fig. 5*b*). In *Kelloggella* and *Kraemeria* (Fig. 5*d*) the two epiotics meet narrowly on the midline behind the supraoccipital; in *Microdesmus* broadly.

In *Gobiodon* there is a crest running along the whole middorsal line of the skull from above the mesethmoid to the exoccipitals. In *Eviota* there is a moderately developed crest on the supraoccipital. The other genera examined have at most a small knob on the supraoccipital, not even that in *Kelloggella*.

The parietals in the gobioid fishes seem to be absent invariably. Among the fishes dealt with here the area the parietals would normally cover is filled in two different ways. In *Eleotris*, *Ptereleotris*, *Awaous*, and *Kraemeria* (Fig. 5*d*) the parietal region is covered by the frontals which run back along the sides of the supraoccipital to the epiotics; the sphenotic in these fishes is small. In *Eviota* (Fig. 5*b*), *Kelloggella*, *Gobiodon*, and *Microdesmus* the sphenotic extends across the upper surface of the skull on each side to the supraoccipitals, thus separating the frontals from the epiotics.

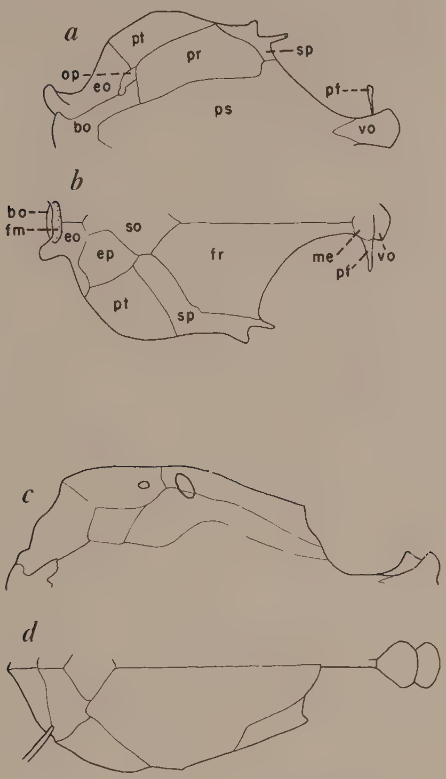

FIG. 5. Skull of *Eviota*, *a*, *b* (*a*, left half from above; *b*, left half from below) and of *Kraemeria*, *c*, *d* (*c*, right half from below; *d*, right half from above). BO, basioccipital; EO, exoccipital; EP, epiotic; FM, foramen magnum; FR, frontal; ME, mesethmoid; OP, opisthotic; PF, prefrontal; PR, prootic; PS, parasphenoid; PT, pterotic; SO, supraoccipital; SP, sphenotic; VO, vomer. The non-ossified area on the ventral surface of the *Kraemeria* skull is partly stippled.

In all the gobioid fishes at hand the skull is abruptly narrowed between the orbits. In the interorbital region the dorsal surface of the skull may be flat as in *Eleotris* and *Awaous*, form a concave trough as in *Ptereleotris* and *Eviota*, or a narrow ridge as in the other genera. The prefrontals are always rather small and may be firmly attached to the skull, more or less movably attached, or completely free as in *Kraemeria* (Fig. 1).

The vomer is toothless in the genera under discussion.

There is no basisphenoid.

The individual bones of the lower surface of the cranium of some of these fishes are not sufficiently well demarcated to allow their certain determination. Consequently, only two bones in this area will be mentioned. The alisphenoids appear to be lacking and, so far as I am aware, are unknown in gobioid fishes. With regard to the opisthotics, Regan (1911: 729) states that these bones are, "large, reaching basioccipital and separating exoccipitals from prootics." Actually, the opisthotics appear to be very variable in the gobioid fishes. In *Awaous* they agree well with Regan's statement and his figure of *Eleotris marmorata* (1911: 730, fig. 1). In *Eviota*, however, the opisthotics are quite small (Fig. 5*a*). In *Kelloggella* and *Kraemeria* they appear to be altogether lacking, and in this agree with *Mistichthys luzonensis* (Te Winkel, 1935: 473). It seems certain that the opisthotics are of no value as a distinguishing character for the gobioid fishes.

Pectoral Girdle

The pectoral girdle shows various stages of degeneration among the fishes examined here.

Regan (1911: 729) states that the posttemporal is forked in gobioid fishes. This is true for the various species investigated except *Kelloggella* and *Kraemeria*. In *Kelloggella* the lower prong of the fork is made up of a ligament at the end of which is a minute ossification (which may possibly represent the detached opisthotic). In *Kraemeria* the posttemporal is a simple strut.

The pectoral radials are said by Regan (1911: 729) to be, "4, large, laminar, united to form a plate." This is more or less true of all the species dealt with here except *Kraemeria*, which has only three actinosts (Fig. 6). It seems probable that the uppermost actinost is the missing one, as this one is reduced to a very weak strut in *Kelloggella*.

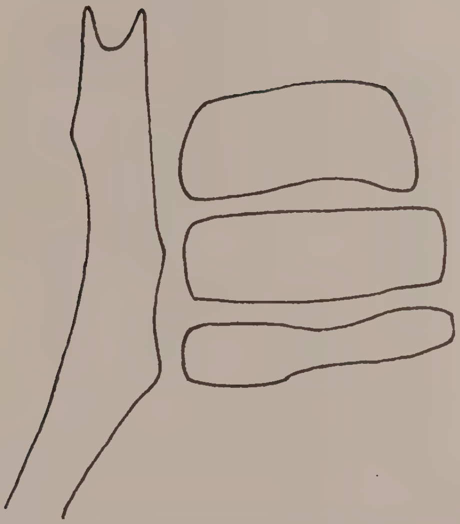

FIG. 6. Left pectoral girdle, from outside, of *Kraemeria* showing cleithrum and the three actinosts.

Regan uses the primary pectoral girdle as a method of distinguishing between the Eleotridae and Gobiidae. Of the Eleotridae Regan (1911: 730) states: "Hypercoracoid [scapula] and hypocoracoid [coracoid] well developed; radials [actinosts] inserted on hypercoracoid, hypocoracoid, and on the ligamentous or cartilaginous tissue between these bones;" of the Gobiidae: "Hypercoracoid absent; radials inserted on the cleithrum, only the lowest in contact with the hypocoracoid."

Among the larger or better ossified skeletons *Eleotris* and *Eviota* have a scapula and *Gobiodon* and *Awaous* do not. However, among the more weakly ossified pectoral girdles which include *Microdesmus*, *Ptereleotris*, *Kelloggella*, and *Kraemeria* I can find neither coracoid nor scapula. Consequently I can only conclude that the osteological characters of the pectoral girdle, if valid, are extremely difficult to use.

Vertebrae

Regan has given the vertebral number among gobioid fishes as 25 to 28 for the Eleotridae and 25 to 34 for the Gobiidae. Among the species investigated here *Ptereleotris*, *Eviota*, *Kelloggella*, *Gobiodon*, and *Kraemeria* each has 26 vertebrae. However, the vertebral count given by Reid (1936: 71) for *Microdesmus multiradatus* is 62, and the range of vertebral variation found by Reid in the genus *Microdesmus* is 42 to 62. Smith (1951: 521) gives the vertebral count of his *Paragobioides copleyi* as 59. Thus *Microdesmus* and *Paragobioides copleyi* have vertebral counts lying well beyond the normal vertebral range in the Gobioid fishes. It is true that these two genera are made up of far more elongate fishes than the usual goby. Nevertheless, there are other elongate gobioids that so far as known do not have more than 34 vertebrae (cf. Hora, 1924: 156).

Caudal Skeleton

The caudal skeleton of the gobioid fishes (Fig. 7*a–c*) appears to be highly diagnostic. Above and below the main wings of the hypural fan are small splint-like bones. In front of the upper splint is a large plate-like ossicle that appears to lie free in the membrane above the urostyle, or which, in *Awaous*, is attached along its anterior edge to the preurostylar neural spine. These main features of the gobioid caudal skeleton seem to be constant in all of the species examined; variations in some of the minor features are illustrated in Figure 7*a–c*.

The small island of bone above the urostylar vertebra does not seem to be essentially different from that found in the typical percoid *Epinephelus*. However, *Epinephelus* and most other perciform fishes (Fig. 7*d–f*) examined do not have the splint-like bones above and below the hypural fan. Smith's figure of *Paragobioides copleyi* (1951: 522, fig. 1E) does not show these splints either, but as they are small they may have been overlooked.

Fins

In the fishes dealt with here there is either approximately (*Eleotris*, *Microdesmus*) or exactly (*Awaous*, *Kelloggella*, *Eviota*, *Gobiodon*, *Kraemeria*) one soft dorsal (or anal) ray per vertebra in the region occupied by these fins. *Ptereleotris* differs rather sharply from the foregoing genera in having two or three soft rays per vertebra.

All of the genera examined except *Microdesmus* have a separate spinous dorsal of five or six soft spines, the last of which is somewhat separated from the others; the interneural of the first spine extends between the 3rd and 4th neural arches and the last between the 7th and 8th neural arches. In *Microdesmus* the dorsal is a single undifferentiated fin the first interneural of which lies between the 4th and 5th vertebra.

The number of principal caudal rays is indeterminable in several of the species investigated.

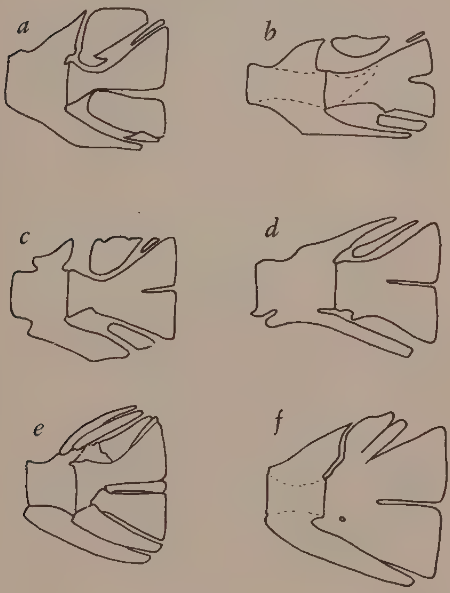

FIG. 7. Caudal skeleton of three gobioids (*a*, *Ptereleotris*; *b*, *Kraemeria*; *c*, *Kelloggella*), of two percoids (*d*, *Crystallodytes cookei* (Trichonotidae); *e*, *Ammodytes tobianus*), and of a blennioid (*f*, *Istiblennius gibbifrons* (Blenniidae)).

The pectoral fin is more or less rounded in all of these species. The number of pectoral rays is 12 in *Microdesmus* and only 8 in *Kraemeria*. The low number of pectoral rays in *Kraemeria* is probably correlated with the degeneration of the pectoral girdle in this fish.

The pelvic fins of *Eleotris*, *Ptereleotris*, *Eviota*, *Kraemeria*, and *Microdesmus* are separate. Those of *Awaous*, *Gobiodon*, and *Kelloggella* are fused. There are five soft rays in the pelvic fins of all except *Eviota*, which has four, and *Microdesmus*, which appears to have only three soft rays.

RELATIONSHIPS

I believe there can be no question regarding the allocation of *Microdesmus* and *Kraemeria* to the gobioid fishes. Both of these genera agree with most of the characters by which the gobioid fishes have been and can be defined: the absence of parietals from the skull and the peculiarities in the suspensorium, hyoid arch, and caudal skeleton. In all these features *Microdesmus* and *Kraemeria* disagree with both the blennioid and the trichonotid fishes.

By contrast the chief features by which these two genera can be and have been separated from the gobioid fishes are as follows.

In *Kraemeria* the gill openings extend rather far forward, but they also do in the gobioids *Glossogobius*, *Chaenogobius*, and *Trimma* (Schultz, 1943: 223, 248). The epiotics meet below the supraoccipital, but they also do in *Kelloggella* as noted above. The opisthotics are absent, but Te Winkel has been unable to find opisthotics in *Mistichthys* and I have been unable to find them in *Kelloggella*. The lower fork of the posttemporal is lacking, but it also is in *Kelloggella*. Finally, the pectoral girdle and fin are greatly reduced, but in this *Kraemeria* merely shows a terminal stage in a reduction demonstrated in other gobioids.

Microdesmus differs from the typical gobioids chiefly in the great elongation of the body and in the apparently correlated increase in number of vertebrae and change in dorsal fin structure. In the typical gobioids the vertebral number is apparently around 26, but in some of the more elongate species the number reaches 34. *Microdesmus*, with 42 to 62 vertebrae seems to be simply the terminal point in a line of gobioid specialization for which intermediate steps are known. The absence of a separate spinous dorsal fin is also known in other gobioid genera, most of them again elongate forms; in many of these the dorsal spines are poorly differentiated from the soft rays.

It may be well, at this point, to summarize the salient characters which would seem to distinguish the Gobioidei, including *Kraemeria* and *Microdesmus*, from other suborders of the Perciformes.

Parietals lacking. Branchiostegals (4) 5 or 6, the first one or two well separated from the others. Mesopterygoid narrow or absent. Preopercle and symplectic widely divergent above, with an interspace between them. Hypurals with a splint-like bone above and below.

A host of less diagnostic characters might be added. Nevertheless, it is necessary to weed out of the existing diagnoses of the gobioid fishes, for example those of Regan (1911: 729) and Koumans (in Weber and de Beaufort, 1953: 1), a number of the features usually listed.

The pelvic fins may be reduced (*Microdesmus*) beyond, "4 or 5 soft rays." The epiotics are not always (*Kelloggella*, *Microdesmus*, and *Kraemeria*), "separated by the supraoccipitals." The opisthotic is not always large (*Eviota*, *Kelloggella*, *Kraemeria*). The lower pharyngeals are not always separate (*Awaous*, *Kraemeria*). The posttemporal is not always forked (*Kelloggella*, *Kraemeria*). There may be only three actinosts (*Kraemeria*). Finally, the number of vertebrae may be very much greater than 34 (*Microdesmus*).

Before attempting to establish the position of *Microdesmus* and *Kraemeria* within the Gobioidei it may be well to list in phylogenetic key form the principal osteological differences between the various forms here examined.

1a. Branchiostegal rays 6 . . . . **Eleotris**
1b. Branchiostegal rays 5.
  2a. Two or three soft dorsal interneurals to each neural spine . . . . **Ptereleotris**
  2b. Usually one soft dorsal interneural to each neural spine.
    3a. Fewer than 30 vertebrae; a separate spinous dorsal fin of 5 or 6 spines.
      4a. Four actinosts and 12 or more pectoral rays; gill membranes broadly attached to the isthmus.
        5a. No crest running along the whole top and back of head; branchial arches without or with weakly-developed gill rakers.
          6a. Lower pharyngeals separate; sphenotics meeting the supraoccipital.
            7a. Epiotics separated by the supraoccipital; pelvics separate . . . . **Eviota**
            7b. Epiotics meeting behind the supraoccipital; pelvics united . . . . . . **Kelloggella**
          6b. Lower pharyngeals fused; sphenotics not meeting the supraoccipital . . . . . **Awaous**
        5b. A crest running along the top and back of skull; branchial arches with two rows of spinous gill rakers . . . . **Gobiodon**
      4b. Three actinosts and 8 pectoral rays; gill membrane narrowly united to the isthmus . **Kraemeria**
    3b. Sixty-two vertebrae; no separate spinous dorsal fin . . . . . **Microdesmus**

This synopsis indicates the general opinion that in the Gobioidei *Eleotris* is undoubtedly nearest to the basic percoid stock from which the gobioids appear to have arisen. Beyond *Eleotris* there would seem to be a number of lines of specialization as well as a major grouping around the typical gobies. With the meager amount of material at hand it seems impossible to delimit these adequately or properly. About all that can be said is that a division between the gobioid fishes with ventrals separate and those with ventrals united may be convenient, but that it probably does more to obscure than to clarify the true phylogenetic sequences within the Gobioidei.

KRAEMERIIDAE

As noted by numerous authors, e.g., Schultz (1943: 262), the genus *Kraemeria* has been described at least three times, i.e., as *Kraemeria* (Steindachner, 1906: 41), and *Vitreola* (Jordan and Seale, 1906: 393) from Samoa, and as *Psammichthys* (Regan, 1908: 246) from the Seychelles. The genus has been placed among the gobioids by Jordan and Seale (1906: 393), Regan (1911: 733), etc., and with the trichonotids by Regan (1908: 246), Fowler (1938: 300), Schultz (1943: 262), etc. A family (Psammichthyidae) was first erected for it by Regan (1911: 733).

Aside from *Kraemeria* only two other genera seem to have been attributed to the Kraemeriidae. One of these is *Gobitrichonotus* Fowler (1943: 85). This genus would seem to differ from *Kraemeria* chiefly in that the pelvics are fused and the two dorsal fins are completely separate. In these features *Gobitrichonotus* is intermediate between the typical gobies and *Kraemeria*, thus making the Kraemeriidae more difficult to define.

More recently Whitley (1951: 402) has described the rather nondescript genus *Parkraemeria* as a kraemeriid. Whether or not this fish is actually related to *Kraemeria* I am unable to judge.

The question of the rank to be attributed to *Kraemeria* and *Gobitrichonatus* within the Gobioidei cannot be finally determined until more is known about the other forms of the suborder. Tentatively, and in part because it causes no nomenclatorial innovation (cf. Berg, 1940: 487), the two genera *Kraemeria* and *Gobitrichonotus* may be recognized as a family Kraemeriidae. The family may, perhaps unsatisfactorily, be distinguished from other gobioid families as follows:

Scaleless, small-eyed gobioid fishes with a projecting chin. Gill openings extending rather far forward, the gill covers narrowly attached to the isthmus. Pectoral rays 8 or 9. Dorsal and anal free from the caudal. Pelvics separate or united. Dorsals separate or united.

If *Parkraemeria* actually belongs to the Kraemeriidae several of the diagnostic features given above will have to be omitted, leaving a rather weak residue, for *Parkraemeria* lacks a projecting chin and has large eyes and 15 pectoral rays.

MICRODESMIDAE

The microdesmids, to my knowledge, have been universally treated as blennioid fishes, and have been accorded family status, c.f. Regan (1912: 274). The Microdesmidae consists, according to Reid (1936), of a single genus *Microdesmus* described by Günther (1864: 26) containing 10 species from both coasts of tropical America and from the Cameroons. However, certain species from the tropical western Pacific not included by Reid apparently also belong with the microdesmids. In 1858 Bleeker described the genus *Gunnellichthys* from the East Indies. Jordan (1923: 233) placed this genus in his provisional family Chaenopsidae, and de Beaufort (in Weber and de Beaufort, 1951: 447) allocated it to the Pholidichthyidae. It appears, from evidence presented below, that *Gunnellichthys* must not only be extracted from the above families but removed from the blennioid fishes altogether and placed with *Microdesmus* among the gobioids.

Kendall and Goldsborough (1911: 324) described the genus *Paragobioides*, based on *P. grandoculis* from the Marshall Islands. This species has been allocated to the percoid family Trichonotidae by Fowler (1938: 206) as well as to the gobioid Taeniodidae (Hora, 1924: 162). It was supposedly redescribed from Line Island specimens by Fowler (1938: 206), but since Fowler's redescription states in part: "gill openings wide, extend well forward," there seems some doubt that Fowler had Kendall and Goldsborough's species.

In 1951 Smith described *Paragobioides copleyi* and erected for the genus the family Paragobioididae, which he places near the Ammodytidae and Trichonotidae. As Dr. Strasburg first pointed out to me, Smith's description and figure of *Paragobioides copleyi* differ in only minor respects from those given by de Beaufort (*loc. cit.*) for *Gunnellichthys pleurotaenia*. (In *Gunnellichthys pleurotaenia* the dorsal and anal fins are said to be attached by a low membrane to the caudal; in *Paragobioides copleyi* the dorsal and anal are said to end before the caudal base. In *G. pleurotaenia* the pelvic rays are said to be 2; in *P. copleyi* they, "vary from 4–6." In *P. copleyi* the chin protrudes; in *G. pleurotaenia*, the figure does not show a protruding lower jaw.) It would seem therefore that *Paragobioides copleyi* and *Gunnellichthys pleurotaenia* may well be congeneric.

Another species with a banded color pattern similar to those of *Gunnellichthys pleurotaenia* and *Paragobioides copleyi* is "*Cerdale*" *bilineatus*, rather briefly described but not figured by Clark (1935: 394) from the Galapagos. About all that can be said from Clark's description is that his species most probably belongs in the *Gunnellichthys-Paragobioides-Microdesmus* group.

The differences between *Paragobioides copleyi* and *P. grandoculis* would seem to be of about the same magnitude as those separating the former species from *Gunnellichthys pleurotaenia*. Smith has already noted (*op. cit.*: 521) the more anterior origin of the pectoral and the different coloration of *P. copleyi*. In addition, unlike *P. copleyi*, the dorsal rays of *P. grandoculis* are said to be "somewhat produced beyond membrane."

Without specimens at hand it seems futile to try to determine whether *Microdesmus*, *Gunnellichthys*, and *Paragobioides* are separate and valid genera. It may be that all three will have to be combined into a single genus (*Gunnellichthys*) but in order to make as few nomenclatorial changes as possible the three genera may provisionally be maintained as separate. They may be separated, probably artificially and certainly unsatisfactorily, by the following key:

1a. Pelvic soft rays 2 or 3.
  2a. Body without a well marked longitudinal stripe. Dorsal and anal united to the caudal by a membrane ....**Microdesmus**
  2b. Body with a well-marked longitudinal stripe.
    (3a. Dorsal and anal free from the caudal ......**"Cerdale" bilineatus** Clark)
    3b. Dorsal and anal connected with the caudal by a low membrane........ ....**Gunnellichthys**
1b. Pelvic soft rays 4 to 6. Caudal free from the dorsal and anal...**Paragobioides**

The osteology of *Microdesmus multiradiatus* has been dealt with above. That of *Paragobioides copleyi* has been described by Smith (1951). The main differences I can find between these two accounts are as follows. In *P. copleyi* the radials of the first few dorsal rays are said, and shown (Smith, 1951: 521 and fig. 1B), to be quite isolated and subhorizontal; in *Microdesmus* they are well developed and interdigitate with the tips of the neural spines. In *P. copleyi* the pectoral girdle is well ossified and exactly as described and shown by Regan for the Gobiidae; I am unable to determine the details of the pectoral girdle structure in *Microdesmus*. The skull is said to be highly cartilaginous in *P. copleyi* (in which the total length of the fish was only 2 to 3 inches), whereas in a skeleton of *M. multiradiatus* (5.5 inches in length) the skull is well ossified. In *P. copleyi* there is said to be a large mesopterygoid, but I believe that this bone is really the pterygoid, as no pterygoid is shown in Smith's figure (1951: 522, fig. 1). Smith also shows (same fig.) the ceratohyal as a bone of even depth throughout, whereas in *Microdesmus* the ceratohyal is abruptly deepened posteriorly. Again in *P. copleyi* there are, as mentioned above, no splint-like bones shown (Smith, 1951: 522, fig. 1E) above and below the hypural fan, but this I suspect may be an omission. These differences are in no way significant, in my opinion.

The family to which these genera belong may provisionally be called the *Microdesmidae* (following Regan, 1912; Reid, 1936; etc.). The peculiarities of the family within the suborder Gobioidei consist chiefly of the elongation of the body with the correlated increase in vertebral number and the continuous dorsal fin without distinction between spines and rays. In addition, however, it has a peculiar maxillary structure in that the maxillaries send out anterior prolongations which meet or nearly meet each other on the midline in front of the premixillary pedicels.

The family thus defined seems to be of circumtropical distribution. The Microdismidae, however, have been associated hitherto with temperate blennioid families. From these they can, I believe, be differentiated externally by having two widely separated nostrils on each side of the head, one near the snout rim and the other just in front of the eye. Internally, they can be separated by any of the gobioid features listed above, and also by the complete absence of a circumorbital ring of bones. The elimination of the tropical microdesmids from the temperate series of blennioid families seems logical geographically as well as phylogenetically.

Among tropical groups the Microdesmidae may perhaps most easily be confused superficially with the Trichonotidae or certain of the tropical blennioid groups, e.g., the Pitroscirtinae, Xiphasiidae, Congrogadidae, etc. From the Trichonotidae the Microdesmidae may be differentiated externally by the presence of small, round, somewhat embedded scales. From the blennioid groups the Microdesmidae may perhaps most easily be separated superficially by the fact that the anterior nostril lies about on the snout rim (well above the snout rim in blennies so far as I can determine).

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DERMATITIS DUE TO CONTACT WITH THE HYDROID, SYNCORYNE MIRABILIS (AGASSIZ, 1862)

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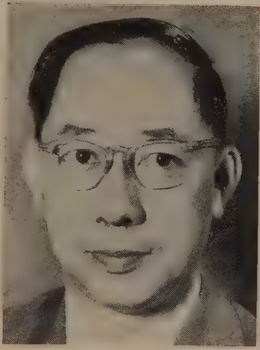
DERMATITIS resulting from contact with marine hydroids (phylum Coelenterata) has been observed many times in the Hawaiian Islands by the authors. De Oreo,[1] in 1946, reported 52 cases from the island of Oahu which he attributed to contact with Halecium beani. However, we believe the following account to be the first incriminating free-floating parts of hydroids (rather than the attached colony) and the first implication of the species, Syncoryne mirabilis.


DR. CHU

Data and Discussion

The area near the mouth of the Wailoa River in Hilo Harbor was visited on November 22, 1954,[2] to determine the cause of dermatitis occurring among construction men working on a small boat pier (Fig. 1). During the previous month approximately twelve men who had entered the water to work on the pier were reported to have contracted a dermatitis of variable severity.

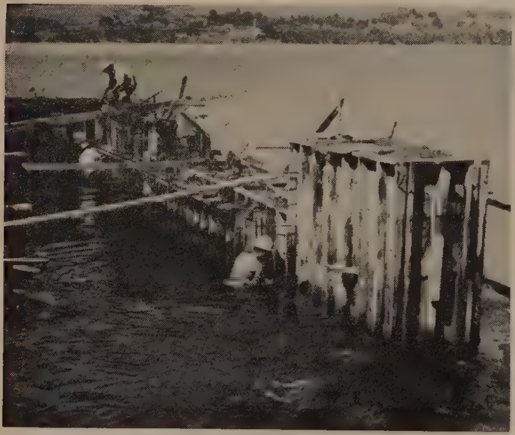


FIG. 1—Area of operations in Hilo Harbor near the mouth of the Wailoa River.

Three men exhibiting dermatitis of about two weeks' duration were examined. Of these one man had almost recovered, a second (Fig. 2) bore purple scars one-fourth to one-half inch in diameter upon his legs and abdomen, and the third had fewer and smaller lesions of the same type, several of which had become purulent sores. All three men claimed to have experienced a prickling sensation while immersed in the water. Six to twelve hours later an intensely itching, dispersed, papular eruption appeared and persisted for several days before subsiding. The lesions were most numerous on areas of the body that had been covered with clothing (most of the men worked in the water fully clothed) but were also present on uncovered parts.

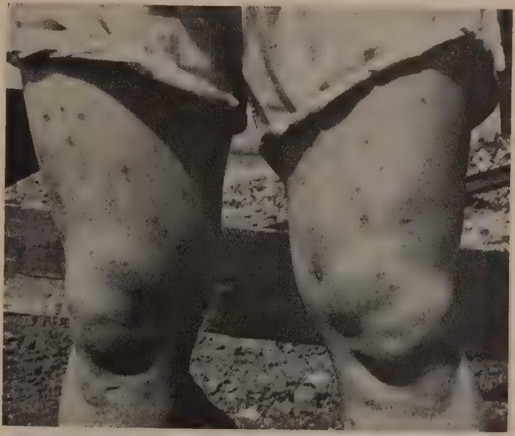


FIG. 2—Sequelae of focal skin lesions on thighs of one man.

Examination of the rocky shore and bottom in the immediate vicinity of the pier revealed that

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[1] De Oreo, G. A.: Dermatitis venenata resulting from contact with marine animals (hydroids); report of cases. Arch. of Dermatol. and Syphilol. 54:637 (Dec.) 1946.

[2] The authors appreciate the courtesy and assistance extended during the study by the personnel of James W. Glover, Ltd., and the Hilo Branch of the Department of Health, T. H.

many of the large, submerged lava rocks were covered with a small hydroid which was later identified as Syncoryne mirabilis[3] (Fig. 3). While searching for possible dermatitis-producing organisms the junior author noticed that walking on the hydroid-covered rocks dislodged the hydroids, their medusae, or their tentacles, and these free-floating pieces, carried against him by the surging water, caused a prickling sensation. This experience, together with the nature and distribution of the lesions on the men, showed that the dermatitis was contracted from floating polyps, tentacles, and medusae and not from contact with the attached colonies.

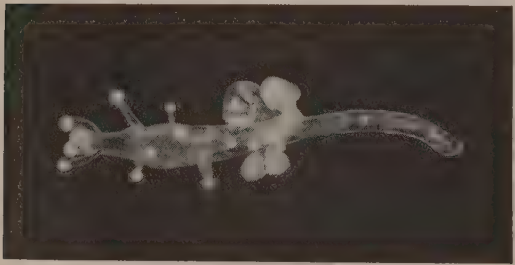

FIG. 3—Syncoryne mirabilis.

Small colonies of freshly collected Syncoryne were applied to the upper arms and abdomens of the authors and one man who had previously contracted dermatitis at the pier. In this test all three persons experienced a prickling sensation and a reddening of the area exposed to the hydroid. No dermatitis appeared on the authors; but after about ten hours, a fine papular eruption occurred on the man who had previously had dermatitis (Fig. 4).

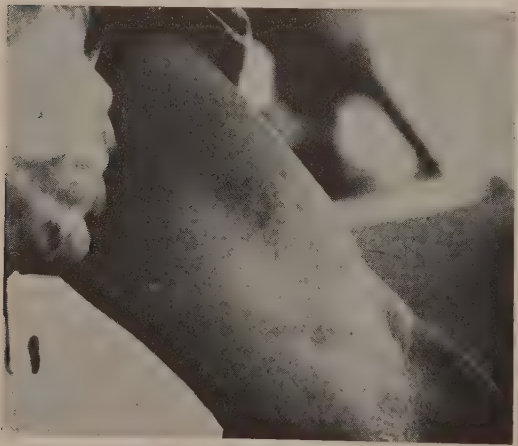

FIG. 4—Patch test site on arm of one dermatitis victim after ten hours.

In response to a plea for relief of the men's discomfort, several methods of control were considered. The small confined area in which the men worked and the swift current around the pier (Fig. 1) excluded possibilities of complications resulting from the use of a chemical control agent. With these considerations in mind large crystals of copper sulfate were scattered over the bottom at the rate of about 30 pounds per 5,000 square feet. The use of large crystals brought about a higher concentration of the reagent near the bottom where the hydroids grew. Examination of the rocks ten hours after the application of copper sulfate showed that the hydroids were dead and, in fact, the polyps were decomposed and washed away.

The specimens of hydroids taken at the pier in Hilo, Hawaii, agree well with Syncoryne mirabilis (Agassiz, 1862).[4] It is a cosmopolitan species and is usually less than one centimeter in height, although the colonies may spread over an area of several square feet. The erect polyps arise from creeping stolons and bear fifteen or more capitate tentacles. The medusoid generation (the medusae of Syncoryne bear the generic name, *Sarsia*) appear below the tentacles where they attain sexual maturity before liberation from the polyp (Fig. 3). Reference to an extensive personally compiled bibliography on all types of invertebrate-induced dermatitis indicates this to be the first time hydroids of the genus Syncoryne have been incriminated as dermatitis producers.

Summary and Conclusion

Investigation of an outbreak of dermatitis among men working in the water on a small boat pier near the mouth of the Wailoa River in Hilo Harbor, Hawaii, was shown to be caused by the hydroid, Syncoryne mirabilis (Agassiz, 1862).

The dermatitis resulted from contact with pieces of the hydroid colony (scuffed from the rocks by the men's walking on them) which were carried beneath the clothing and against the men by the surge of the water. The ensuing dermatitis was of variable severity and usually did not persist for more than three weeks.

A thorough search of literature on cases of invertebrate-induced dermatitis indicates this may be the first time hydroids of the genus Syncoryne have been incriminated as dermatitis producers.

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[3] Fraser, C. M.: Hydroids of the 1934 Allan Hancock Pacific Expedition. Allan Hancock Pacific Expeditions 4 (1):7, 15, 1938.

Fraser, C. M.: Hydroids of the Pacific Coast of Canada and the United States, p. 28, pl. 3, 1937, and Hydroids of the Atlantic Ocean, p. 41, pl. 4. The University of Toronto Press, Toronto, 1944.

[4] Agassiz, L.: Cont. Nat. Hist. U. S. 4:185; 3, figs. 1-16, plate 17, figs. 1-14, plate 18; figs. 1-27, plate 19. 1862.

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An Analysis of the Genera of Surgeon Fishes (Family Acanthuridae)[1]

JOHN E. RANDALL

THE GENERA OF FEW families of tropical marine fishes have been as badly confused as those of the Acanthuridae. Ahl (1923: 36) and others have pointed out the need for a review of the generic classification of the family. As may be seen in the key below, the genera are easily distinguished; most of the inconsistency with respect to use of names has been purely nomenclatorial.

The genera fall into two major groups on the basis of the armature of the caudal peduncle. Four of them, *Acanthurus*, *Ctenochaetus*, *Zebrasoma*, and *Paracanthurus*, are characterized by a single folding spine on each side of the peduncle. *Naso* and *Prionurus* have one to six fixed spines or plates in this region. Such a clear-cut distinction might tempt one to treat the two groups as subfamilies. There is, however, a sharing of other important characters by various genera in both groups which makes such a consideration untenable. In this paper the phylogenetic interrelationships of the surgeon fish genera are discussed, and an attempt is made to put the generic classification in order.

The four genera with the single folding spine on the caudal peduncle are being revised. The revision of *Ctenochaetus* is completed (Randall, 1955). Those of *Zebrasoma*, *Paracanthurus*, and *Acanthurus* will follow.

KEY TO THE GENERA OF ACANTHURIDAE

1a. 1 to 6 immovable keel- or thorn-like spines or laminae on each side of caudal peduncle; least depth of caudal peduncle contained 3.5 to 6 times in length of head; dorsal and anal spines stout.....2

1b. A single folding spine on each side of caudal peduncle; least depth of caudal peduncle contained 2.1 to 3.5 times in length of head; dorsal and anal spines slender (except *Paracanthurus*) 3

2a. 1 to 2 pairs of caudal spines or laminae; pelvic fin rays I, 3; anal spines II; dorsal spines IV to VII; teeth small, conical with tips slightly compressed, smooth or with very small denticulations. (Indo-West-Pacific)..................**Naso**

2b. 3 to 6 pairs of caudal spines or laminae; pelvic fin rays I, 5; anal spines III; dorsal spines VIII or IX; teeth moderately large, flattened, close-set, with large denticulations. (Japan, Australia, tropical eastern Pacific, Galapagos Islands).... ....**Prionurus**

3a. Pelvic fin rays I, 3; scales on head modified to tuberculated plates. (Indo-West-Pacific)...............**Paracanthurus**

3b. Pelvic fin rays I, 5; scales on head not modified to tuberculated plates.......4

4a. Dorsal spines VI to IX (usually VIII or IX); length of longest dorsal ray contained 3.5 to 6 times in standard length;

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[1] A portion of a thesis submitted to the Department of Zoology, University of Hawaii, in partial fulfillment of the requirements for the degree of Doctor of Philosophy. Contribution No. 67 of the Hawaii Marine Laboratory in cooperation with the Department of Zoology and Entomology, University of Hawaii. Manuscript received November 8, 1954.

scales not elevated and ctenii not long; least depth of caudal peduncle 2.1 to 3.2 in length of head; caudal peduncle spine in a sharply-defined groove 5

4b. Dorsal spines IV or V; length of longest dorsal ray contained 2.2 to 3.8 times in standard length; scales elevated and with long ctenii; least depth of caudal peduncle 3 to 3.5 in length of head; caudal peduncle spine in a shallow depression. (Indo-West-Pacific) . . . . . . **Zebrasoma**

5a. Teeth fixed, not attenuate with expanded incurved tips, denticulate on both lateral and medial margins, and not over 26 in upper jaw; dorsal spines IX (except one species with VI or VII and two with VIII). (Circumtropical) . . . **Acanthurus**

5b. Teeth movable, attenuate with expanded incurved tips which bear only lateral denticulations, and from 30 to 60 in upper jaw (of specimens over 75 mm. in standard length); dorsal spines VIII. (Indo-Pacific) . . . . **Ctenochaetus**

The relationship of the existing genera of surgeon fishes is not easily fitted into a conventional family tree pattern. Aoyagi (1943: 196) has constructed such a tree for the Acanthuridae on the basis of dentition alone. For this one character his conclusions are well drawn. *Naso*, with its conical teeth, is listed as most primitive. *N. lituratus* (Bloch and Schneider) and *N. unicornis* (Forskål) exemplify those species of this genus which have teeth lacking denticulations. Others, like *N. hexacanthus* (Bleeker), have tiny denticulations and are higher in the evolutionary sequence. *Prionurus*, *Paracanthurus*, *Zebrasoma*, and *Acanthurus* are progressively more specialized, though these four genera are basically similar. The teeth have become close-set, flattened, and strongly denticulate. *Ctenochaetus*, which has comb-like teeth, is portrayed as being derived from *Acanthurus*.

This picture is strengthened by a consideration of food habits of the genera. The acanthurids, in general, are herbivorous. *Naso* tends to feed on leafy algae such as *Sargassum;* its teeth are not efficient for feeding on slick, filamentous algae. The flattened, denticulate teeth of the next four genera might represent a specialization for feeding on fine algae. *Ctenochaetus* with its numerous, long, protruding teeth can feed effectively on loose algal filaments and other detrital material on the bottom.

When, however, characters other than dentition are considered, the interrelationships of the genera are not so simple. *Naso* and *Prionurus*, both with fixed caudal spines, have different numbers of pelvic rays. *Paracanthurus*, which has a movable caudal spine and is separated from *Naso* by *Prionurus* in the phyletic line of Aoyagi, has a pelvic formula of I, 3 like *Naso*. It appears then that the reduction in pelvic fin rays from I, 5 to I, 3 must have occurred independently in *Naso* and *Paracanthurus* or that the I, 5 condition was secondarily regained in *Prionurus*. The dorsal spines in *Naso* are IV to VII. In *Prionurus* and *Paracanthurus* they are VIII or IX. In *Zebrasoma* they drop to IV or V, and in *Acanthurus* and *Ctenochaetus* they increase again to VIII or IX. The scales present an even more perplexing problem. The supposedly advanced genera, *Acanthurus* and *Ctenochaetus*, have ctenoid scales which are less specialized than the unusual raised and often spinulous scales of the other genera. It is difficult to place *Acanthurus* in a more primitive position than *Naso*, however, for it does not seem that a folding caudal spine and denticulate teeth could precede a fixed spine and smooth teeth. Perhaps the linear pattern of evolution postulated by Aoyagi would be less likely than one which supposes that all the Recent genera (except *Ctenochaetus*, which does appear to be derived from *Acanthurus*) arose from common stock at essentially the same period of geologic time.

Eastman (1904*a*) has commented on the sudden appearance in the Eocene of a host of modern teleost types, many of which were as highly specialized then as they are today. The fossil record of the Acanthuridae indicates that both *Naso* and *Acanthurus* date back to the Eocene (Agassiz, 1838; Woodward, 1901; Eastman, 1917), thus these are among the specialized genera making the apparent sudden appearance in the early Tertiary.

Hussakof (1907) recorded a fossil *Zebrasoma* (as *Z. deani*) from the West Indies. The specimen, which was well preserved, was considered possibly of Eocene age. In my opinion this fish is not a *Zebrasoma*. It lacks the great depth of body and elevated fins of this genus. Also there is a very narrow caudal peduncle and a crescentic (high and narrow) caudal fin, and no caudal peduncle spines were located. Of existing genera, it seems closest to *Naso*. This specimen, which was deposited in the American Museum, should be re-examined and its position within the Acanthuridae re-evaluated.

Two extinct genera, *Aulorhamphus* de Zigno (Eocene) and *Apostasella* Whitley (new name for *Apostasis* Gorjanovič-Kramberger) (Oligocene-Miocene) have been included in the Acanthuridae although no caudal peduncle spines have been found for these forms. Ogilby (1916: 173) views "with grave suspicion" the inclusion of these genera in the surgeon fish family. I concur in this doubt.

The fossil *Acanthurus gaudryi* de Zigno and *A. gazolae* Massalongo were considered by Woodward (1901) and Eastman (1904*a*) as not belonging to the genus *Acanthurus*. Woodward believed they might be better placed in the Chaetodontidae. Eastman thought them types of distinct genera, but preferred to include them in *Pygaeus* Agassiz, the limits of which were widely extended by Agassiz. In Jordan's opinion (Eastman, 1904*b*), *Pygaeus* is a generalized type ancestral to the Chaetodontidae, Acanthuridae, and Teuthididae (Siganidae). Berg (1947: 482) thought the VIII or IX anal spines of some *Pygaeus* allies it more closely with the latter than with the other two families.

It is evident that more study of the fossil Acanthuridae and related families is needed, with especial effort to integrate knowledge of fossil with that of present forms and to reconstruct the evolutionary picture in more precise terms.

Genus NASO Lacépède

Naso Lacépède, 1801. Hist. nat. poiss. Vol. 3, p. 105. (Type species by subsequent designation (Valenciennes, 1837, pl. 72, fig. 1), *Naso fronticornis* Lacépède = *Chaetodon unicornis* Forskål.)

Monoceros Bloch and Schneider, 1801. Syst. ichth. p. 180. [Preoccupied by Lacépède (*ex* Plumier), 1798. Hist. nat. poiss. Vol. 1, p. 357, in reference to a balistid.]

Nasonus Rafinesque. 1815. Anal. natur. p. 88. (Substitute name for *Naso*.) [Reference after Gill, 1885.]

Priodon Quoy and Gaimard. Voyage autour du monde . . . *Uranie* . . . Zool. p. 377. (Type species, *Priodon annulatus* Quoy and Gaimard.)

Naseus Cuvier. 1829. Règne animal. Ed. 2, vol. 2, p. 224. (Type species, *Naso fronticornis* Lacépède = *Chaetodon unicornis* Forskål.)

Priodontichthys Bonaparte, 1833. Saggio. distrib. metod. anim. vert. p. 34. (Type species, *Priodon annularis* Cuvier and Valenciennes = *Priodon annulatus* Quoy and Gaimard.) [Reference after Gill, 1885.]

Axinurus Cuvier and Valenciennes, 1835. Hist. nat. poiss. Vol. 10, p. 299. (Type species, *Axinurus thynnoides* Cuvier and Valenciennes.)

Keris Cuvier and Valenciennes, 1835. Hist. nat. poiss. Vol. 10, p. 304. (Type species, *Keris anginosus* Cuvier and Valenciennes.)

Callicanthus Swainson, 1839. Nat. hist. . . . fishes . . . Vol. 2, p. 256. (Type species, *Aspisurus elegans* Rüppell = *Acanthurus lituratus* Bloch and Schneider.)

Ceris Kner, 1865. Akad. Wiss. Wien, Denkschr. 24: 6.

Cyphomycter Fowler and Bean, 1929. U. S. Natl. Mus., Bul. 100, vol. 8, p. 264. (Type species, *Naso tuberosus* Lacépède.) (Proposed as a subgenus; raised to generic rank by Smith, 1951: 1126.)

Prionolepis Smith, 1931. Albany Mus., Rec. 4: 125. (Type species, *Prionolepis hewitti* Smith = *Chaetodon unicornis* Forskål.)

The genus *Naso* has been split by some authors into two or more genera. A frequent basis for this division has been the presence or absence of a horn on the forehead in adults. I do not believe that this is a valid means of separation in view of the late appearance of this character, the difficulty at times in assessing what is a horn and what a mere bony prominence, and the demonstration by Smith (1951: 1126) that the horn occurs only on the male in *Naso rigoletto* Smith.

The use of the name *Axinurus* Cuvier and Valenciennes by Fowler and Bean as a subgenus for *Naso thynnoides* (Cuvier and Valenciennes), which has a single buckler on each side of the caudal peduncle, seems more reasonable than applying this name as a genus as has Smith (1951: 1126).

Quoy and Gaimard (1824: 375) erroneously used the generic name *Aspisurus* Lacépède (= *Acanthurus* Forskål) for a species of *Naso*. Lesson (1830: 151) did the same with *Prionurus* Lacépède. Shaw (1803) applied the name *Acanthurus* to all of the species of surgeon fishes (which included *Naso*) in his *General Zoology*. Jordan and Fowler (1902: 558) used *Acanthurus* for species of *Naso* which have an elongate horn on the forehead in the adult (see section under *Acanthurus* for discussion of this).

Keris and *Prionolepis* were proposed for the late postlarval stage of *Naso*.

Genus PRIONURUS Lacépède

Prionurus Lacépède, 1804. Mus. Natl. de Hist. Nat., Ann. 4: 211. (Type species by monotypy, *Prionurus microlepidotus* Lacépède.)

Xesurus Jordan and Evermann, 1896. Check-list fishes N. and Middle America. P. 421. (Type species, *Prionurus punctatus* Gill.)

Acanthocaulus Waite, 1900. Australian Mus., Rec. 3: 206. (Substitute name for *Prionurus*.)

Burobulla Whitley, 1931. Australian Zoologist 6: 321. (Type species, *Xesurus maculatus* Ogilby.)

Triacanthurodes Fowler, 1944. Acad. Nat. Sci. Phila., Monog. 6, p. 332. (Type species, *Naseus laticlavius* Valenciennes.)

Xesurus is distinguished from *Prionurus* by having three to four instead of six keeled laminae on each side of the caudal peduncle. I do not believe that the number of caudal laminae is of generic significance (a specimen of *Prionurus microlepidotus* Lacépède from Port Jackson, Australia, United States National Museum No. 47964, has five keeled laminae on one side of the caudal peduncle and six on the other), and in view of the lack of other differences, I place *Xesurus* in the synonymy of *Prionurus*. There is less basis for the recognition of *Xesurus* than there is for the division of *Naso* into two or more genera.

As pointed out by Gill (1904: 121) Waite was in error in proposing *Acanthocaulus* as a substitute for *Prionurus*. He did so in the belief that *Prionurus* was established by Lacépède in 1830 instead of 1804. In 1829 *Prionurus* was proposed by Ehrenberg in the Arachnida.

The type species for *Burobulla* Whitley and *Triacanthurodes* Fowler clearly belong in the genus *Prionurus*.

Genus PARACANTHURUS Bleeker

Paracanthurus Bleeker, 1863. Ned. Tijdschr. Dierk. 1: 252. (Type species by monotypy, *Acanthurus hepatus* (Linnaeus) Bloch and Schneider = *Teuthis hepatus* Linnaeus, as restricted by Cuvier and Valenciennes.)

Colocopus Gill, 1885. U. S. Natl. Mus., Proc. 7: 277, 279. (Type species, *Colocopus lambdurus* Gill = *Teuthis hepatus* Linnaeus, as restricted by Cuvier and Valenciennes.)

Günther (1873: 115) and subsequent authors continued to use *Acanthurus* for the one known species of the genus *Paracanthurus* after its proposal by Bleeker. The name *Paracanthurus* was unnoticed until Fowler (1926: 139) pointed out that it preceded *Colocopus* Gill.

Genus ZEBRASOMA Swainson

Harpurus Swainson, 1839. Nat. hist. . . . fishes . . . Vol. 2, p. 256. (Not *Harpurus* of Forster, 1778.)

Zebrasoma Swainson, 1839. Nat. hist. . . . fishes . . . Vol. 2, p. 256. (Type species by monotypy, *Acanthurus velifer* Bloch.)

Scopas Kner, 1865–67. Reise . . . fregatte *Novara* . . . Fische. P. 212. (Type species, *Acanthurus scopas* Cuvier and Valenciennes.) (*Scopas* of Bonaparte, 1831, a *nomen nudum*.)

Laephichthys Ogilby, 1916. Queensland Mus., Mem. 5: 173. (Type species, *Acanthurus rostratus* Günther.)

Bleeker (1851) and other authors after him persisted in using the generic name *Acanthurus* for species of *Zebrasoma*, probably without the realization that the latter had been proposed.

Ogilby established the genus *Laephichthys* for the species *Acanthurus rostratus* Günther on the basis of the unusually long snout and thick dorsal spines as shown in a painting by Garrett. Examination of 13 specimens, among them two collected by Garrett from the Society Islands and probably the ones from which the painting was made, revealed considerable variation in snout length. Some specimens had shorter snouts than the average snout length of *Zebrasoma flavescens* (Bennett) or *Z. scopas* (Cuvier). None had thick dorsal spines. No other differences even approaching generic level could be found between *Z. rostratus* and species of *Zebrasoma*; thus *Laephichthys* is not well founded.

Jordan and Jordan (1922: 66) used the name *Scopas* as a subgenus for *Z. flavescens* to emphasize its distinctness from *Zebrasoma* (*Zebrasoma*) *veliferum* (Bloch). *Z. gemmatum* (Cuvier and Valenciennes) tends to invalidate this subgeneric concept, for it has a tooth structure and fin ray counts approaching that of *veliferum*, yet it lacks the extremely elevated dorsal fin of this species and has a body form more like other *Zebrasoma*.

Von Bonde (1934: 449, fig. 3) described a new species of acanthurid, *Hepatus coccinatus*, from Zanzibar. His description and photograph leave little doubt that his specimens are *Zebrasoma veliferum*, although he gave the dorsal spine count as VII instead of the usual IV.

Genus ACANTHURUS Forskål

Hepatus Gronow, 1763. Zoophylacium . . . p. 113. (Nonbinominal.)

Teuthis Linnaeus, 1766. Syst. nat. Ed. 12, vol. 1, p. 507. (Linnaeus included in *Teuthis* several acanthurids and a siganid under the one name *hepatus*. In Opinion 93 of the International Commission on Zoological Nomenclature the siganid, *T. javus*, was fixed as type.)

Acanthurus Forskål, 1775. Descr. animalium. P. 59. (Type species by subsequent designation (Jordan 1917: 33), *Chaetodon sohal* Forskål.)

Harpurus Forster, 1778. Enchiridion hist. nat. . . . p. 84. (Type species, *Harpurus fasciatus* Forster = *Chaetodon triostegus* Linnaeus.) [Reference after Jordan, 1917.]

Rhombotides Walbaum, 1792. (*ex* Klein, 1775, nonbinominal.) Petri Artedi . . . ichthyologiae pars iii, p. 582.

Aspisurus Lacépède, 1802. Hist. nat. poiss. Vol. 4, p. 556. (Type species, *Chaetodon sohal* Forskål.)

Teuthys Swainson, 1839. Nat. hist. . . . fishes . . . Vol. 2, p. 255.

Ctenodon Swainson, 1839. Nat. hist. . . . fishes . . . Vol. 2, p. 255. (Preoccupied by *Ctenodon* Wagler, 1830.)

Acronurus Gronow, 1854. Cat. fish collected . . . p. 190. (Type species, *Acanthurus argenteus* Quoy and Gaimard.)

Zabrasoma Seale, 1901. Bernice P. Bishop Mus., Occ. Pap. 1: 110.

Harpurina Fowler and Bean, 1929. U. S. Natl. Mus., Bul. 100, vol. 8, p. 253. (Type species, *Hepatus nubilus* Fowler and Bean.) (Proposed as a subgenus; raised to generic rank by de Beaufort, 1951: 165.)

Forskål (1775: 59) proposed *Acanthurus* as a subgeneric category of *Chaetodon*, and in it he included *unicornis*, *sohal*, *nigrofuscus*, and *gahhm* (the latter was considered by him as a variant of *nigrofuscus*). None of these was designated by him as the type species. Lacépède (1801: 105) established the genus *Naso* and listed *unicornis* as a synonym of his *Naso fronticornis* (even though *unicornis* is an earlier name). Also (1802: 556) he removed *sohal* (erroneously as *sohar*) from *Acanthurus* and erected the genus *Aspisurus* for this one species. *Aspisurus* has properly been placed back in *Acanthurus*; *unicornis* remains in *Naso*. Valenciennes (1837, pl. 71, fig. 2) figured *Acanthurus xanthopterus* Cuvier and Valenciennes as the type species of *Acanthurus*. Gill (1885: 278) listed "*Teuthis hepatus* Linnaeus = *Acanthurus chirurgus* Bloch" as the type. Neither of these type designations is valid, for these species were not among those included by Forskål in *Acanthurus*.

Jordan and Fowler (1902: 558) used the genus *Acanthurus* for species of *Naso* which have the frontal horn, under the belief that *unicornis* should be considered as the type of *Acanthurus* since it was the first species listed by Forskål in his subgeneric category *Acanthurus*. I quote Jordan and Fowler: "The first species named by Forskål, *unicornis* being taken as its type, *Acanthurus* becomes equivalent to *Monoceros*." Later Jordan (1917: 33) selected *Chaetodon sohal* Forskål as the type species of *Acanthurus*, and both Jordan and Fowler reverted to the usual use of *Naso*. Should Jordan and Fowler's statement on *unicornis* be construed as a valid type designation, I would recommend application to the International Commission on Zoological Nomenclature to preserve the common usage of *Acanthurus* and *Naso*.

According to Opinion 21 of the International Commission on Zoological Nomenclature, the genera of Klein (1744) do not gain nomenclatorial status by reason of being quoted by Walbaum (1792); thus *Rhombotides* is not valid. Bleeker often used this name instead of *Acanthurus*.

The genus *Harpurina* Fowler and Bean, in which de Beaufort (1951: 165) placed the single species *nubilus* Fowler and Bean, is characterized primarily by small teeth and VI or VII dorsal spines. *Acanthurus thompsoni* (Fowler) and *A. bleekeri* Günther have the same type of dentition (and other similarities), but the usual IX dorsal spines. They serve to connect *nubilus* with more typical species of *Acanthurus;* thus I do not believe that *Harpurina* is a valid genus.

Fowler (1944: 109) established the subgenus *Rhomboteuthis* for the species *Acanthurus coeruleus* Bloch and Schneider on the basis of its deep body, long pectoral fins, and small caudal spine. If only the Atlantic species of *Acanthurus* were classified, such a subgenus might be a useful criterion, but it breaks down when the Indo-Pacific forms are considered, for some, like *Acanthurus guttatus* Bloch and Schneider and *A. nubilus*, have a body depth as great or greater and pectoral fins as long as *A. coeruleus*, and *A. triostegus* (Linnaeus) has a smaller caudal spine. None of these species could be grouped with *coeruleus* to form a natural subgeneric category apart from other species of *Acanthurus*. Better subgenera could be formed by grouping *A. achilles* Shaw, *A. glaucopareius* Cuvier, and *A.*

leucosternon Bennett or *A. nubilus*, *A. bleekeri* Günther, and *A. thompsoni* (Fowler); however, I do not believe that even these are advisable.

The late postlarval *Acanthurus* is quite different from the juvenile. It is more disc-like, transparent in life with silvery abdomen, and naked with vertical striae or folds on the body. It is not difficult to understand why Gronow erected *Acronurus* for this stage and how this genus persisted so long in the literature. Although now well known to be larval, acronurus remains as a common name for the late postlarval stage of *Acanthurus*. Some authors apply the designation to all postlarval acanthurids.

The type species of *Acronurus* by subsequent designation is *Acanthurus argenteus* Quoy and Gaimard. As indicated by Randall (in press), this species may be the young of *Ctenochaetus striatus* (Quoy and Gaimard). If this could be conclusively demonstrated, the generic name *Ctenochaetus* would have to be replaced by *Acronurus*. Under such circumstances, it would be advisable to apply to the International Commission on Zoological Nomenclature to conserve the name *Ctenochaetus*. Nearly all use of *Acronurus* has been for the young of *Acanthurus*.

Swainson (1839) listed *Teuthys* as a surgeon fish genus (an emendation or erroneous spelling for *Teuthis* Linnaeus) for the single species *Acanthurus argenteus* Quoy and Gaimard. His brief description of the genus obviously applies to an acronurus. Linnaeus, however, did not include any acronurus forms in *Teuthis*.

Seale placed in *Zabrasoma* (probably a typographical error for *Zebrasoma*), his new species *agaña* (= *flavescens*) and a species of *Acanthurus* (*A. guttatus*). He apparently mistook *A. guttatus* for a *Zebrasoma* because of its high body.

Genus CTENOCHAETUS Gill

Ctenodon Klunzinger, 1871. Synopsis Fische Rothen Meeres. Pt. 2, p. 509. (Preoccupied by *Ctenodon* Wagler, 1830.)

Ctenochaetus Gill, 1885. U. S. Natl. Mus., Proc. 7: 279. (Type species by original designation, *Acanthurus strigosus* Bennett.)

Ctenodon was first proposed by Wagler (1830) for a reptile. Swainson (1839) used the same generic name for five species of *Acanthurus* and one *Ctenochaetus*. Klunzinger applied the name as a subgenus for the species *Acanthurus ctenodon* Cuvier and Valenciennes (= *Acanthurus striatus* Quoy and Gaimard) and *Acanthurus strigosus* Bennett. Fowler (1904: 545) elevated Klunzinger's subgenus to a genus.

The use by Day (1889: 143) (and subsequent authors) of *Acanthurus* for *Ctenochaetus* (and *Teuthis* for *Ctenochaetus* by Barnard, 1927: 780) appears to be due to ignorance of Gill's name *Ctenochaetus* for this well-differentiated genus.

As is indicated in the discussion of *Acronurus* in the section on *Acanthurus* there is a possible question as to the validity of the name *Ctenochaetus*.

SUPPLEMENTAL NOTE

After the present paper was submitted, an article by Prof. J. L. B. Smith, entitled *East African Unicorn Fishes from Mozambique*, appeared in the South African Journal of Science (65 (6): 169–174). Five genera (here considered only as the single genus *Naso*) and *Prionurus* were split off from the Acanthuridae on the basis of caudal armature and placed in a separate family, the Nasidae.

If only the genera *Naso* and *Acanthurus* were considered, such a division would be tenable. It is not, however, when all of the genera are considered. *Paracanthurus* has the single folding caudal spine, strongly denticulate teeth, IX dorsal and III anal spines like *Acanthurus*, but I, 3 pelvic rays and thickened dorsal spines like *Naso*. *Prionurus*, linked with *Naso* by Smith because of the three to six fixed caudal spines or laminae on each side of the caudal peduncle, has a pelvic formula of I, 5, VIII or IX dorsal and III anal spines, and dentition similar to *Acanthurus*. *Zebrasoma* would seem to be allied with *Acanthurus* in caudal armature and other characters, yet it has a reduced dorsal spine count like *Naso*.

Smith divides *Naso* as here defined into the five genera *Axinurus*, *Naso*, *Cyphomycter*, *Calli-*

canthus, and *Atulonotus*, the latter being erected for the species *Naso hexacanthus* (Bleeker) and *Naso vomer* (Klunzinger). He distinguishes *Atulonotus* from *Axinurus* by its possession of two instead of one plate on each side of the caudal peduncle, teeth with serrate edges; from *Callicanthus* by the presence of pointed teeth and from *Naso* and *Cyphomycter* by the lack of a conical frontal horn or swollen region at all stages. As previously discussed, the number of caudal plates and the presence or absence of a prominence on the forehead are not, in my opinion, characters of generic magnitude in the *Naso* group. Even dentition does not provide a consistent basis for separation. The teeth of *Naso unicornis*, although usually serrate, may be smooth, as indicated in Plate 3, Figure 1 of Aoyagi (1943). Therefore I leave *Naso* undivided and place *Atulonotus* in synonymy.

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A NEW METHOD OF ATTACHING PETERSEN DISK TAGS WITH MONOFILAMENT NYLON[1]

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Several methods of tagging and marking have been attempted in the course of a life-history study of the convict surgeon fish or manini (*Acanthurus triostegus sandvicensis* Streets) in the Hawaiian Islands.[2]

The first tag tried was the Atkins tag (Rounsefell and Kask, 1945), which was fastened by tying with light nylon leader beneath the base of the posterior part of the dorsal fin. At the end of one month all captive fish tagged in this manner had lost their tags.

Next similar tags were threaded through the bony area above the urostyle at the upper base of the caudal fin. These were retained for longer periods; however, all disappeared within six months. Disappointing results with such tags were reported by Fraser (1955) for smallmouth bass.

Petersen disk tags, hand-made from cellulose nitrate, were then tried. Since, among metals commonly used to attach Petersen disk tags, stainless steel seemed most promising from a corrosion standpoint (Calhoun, Fry, and Hughes, 1951), this material was chosen for initial trials. Considerable difficulty was experienced, however, in bending the free ends of the wire on a struggling fish, a disadvantage clearly pointed out by these authors.

An attempt was next made to devise a means of using nylon without resorting to tying knots. Four important disadvantages to the use of this synthetic for tagging when knots must be tied are: knots of nylon are prone to slip; thickness of nylon must be sacrificed to obtain tight knots; a considerable length of nylon is needed for each tying, much of which must be discarded; knot tying is very time consuming in an operation that demands dispatch.

The idea came to mind to melt each free end of the nylon into a little ball. This method proved successful, although there has not been sufficient time to permit any claims of exceptionally long periods of tag retention.

A flame is necessary to obtain sufficient heat to melt the nylon. Heat from a very hot or even glowing object (such as a soldering iron, punk, or cigarette) does not melt the nylon rapidly enough unless the heat-producing object contacts the material. Contact often results in the sticking of the molten nylon to the object.

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[2] This species does not occur in Californian waters. However, methods used on one species are often applicable to others, which may be far removed both geographically and by relationship. The findings contained in this article may therefore be expected to be of significance to fisheries workers both in California and elsewhere. —*Editor.*

The best flame-producing device found to date for tagging is the Ronson Windlite cigarette lighter. The perforated collar at the top of this lighter is more restricted than that of other windproof lighters, and the flame does not flicker as badly in the wind. Jet pipe lighters were tried, but these blew out too readily. A small acetylene torch has been used with success, but is not as convenient as a lighter.

The diameter of the monofilament nylon used measures 0.035 inches. This is sufficiently heavy to avoid the necessity of threading the strand through the back of the fish with a needle. One end of the nylon is melted into a ball and the first disk threaded in place. A dissecting needle is run through the back of the fish below the center of the dorsal fin just above the vertebral column. The dissecting needle should be drawn back and forth several times to clear the hole. The remaining free end of the nylon, which is cut on an angle to form a point, is inserted through the hole, and the second disk put in place. The flame is first used to cut off any excess length of nylon (thus eliminating the need for some cutting instrument such as scissors) and then to melt the end into a knob. The second disk serves as a natural shield against burning the epidermis of the fish during the melting process. The molten nylon requires about 10 seconds to set hard in air. If a fish is released before the nylon sets, the tags may be lost due to sudden flexure of the body of the fish. Setting may be hastened by immersing the newly-tagged fish in a bucket of sea-water while holding the second disk against the side of the body; however, this causes a further loss of tensile strength of the nylon (see below). It is important that a good-sized knob be formed, preferably two to three times the diameter of the nylon filament. If only slightly larger than the hole in the disk, the knob may be forced through the hole. Also, allowance should be made for possible attrition of the knob against rocks or coral. In order to provide for growth, space is left between each knob and adjacent disk. Approximately 3 mm. is needed on each side for growth of small adult manini (which are about 100 to 110 mm. in standard length). Surgeon fishes have compressed bodies (maximum width contained about 1.7 times in head length) and lend themselves well to Petersen disk tagging.

A concrete tank at the Hawaii Marine Laboratory, which measures 34.7 feet by 10.8 feet and is an average 3.9 feet in depth, was made available for testing this method of attaching disk tags to manini. This fish grazes constantly during the day on filamentous algae. In view of the limited amount of substrate for algal growth, only 10 fish were placed in the tank. These ranged from 70 to 96 mm. in standard length. On August 6, 1953, four were tagged, three by using a monofilament nylon and one by stainless steel wire. Seven weeks later all of the fish were caught and measured. The six untagged fish, which had a mean standard length of 86.3 mm., had grown an average of 6.6 mm. The three tagged with nylon (mean standard length 84.4 mm.) grew an average of 7.7 mm. The 93 mm. fish whose disks were attached with stainless steel wire added a smaller increment of growth than any of the other fish, only 2.5 mm. Although these data are insufficient for definite conclusions, it seems apparent that surgeon fish tagged with Petersen disk tags fastened with monofilament nylon are capable of normal growth.

Heavy mortality of captive fish ensued during winter months, possibly because of turbid water following storms or lack of algae in the tank. One of the fish which survived 11 months, until July, when the tank was needed for other purposes, still retained its nylon fastened disks. It was noted that the flesh around the hole pierced by the nylon strand was almost in contact with the nylon. There was no evidence of deterioration of the nylon.

Before the Ronson Windlite lighter was used for tagging, working with a flame was troublesome in waters off Oahu exposed to the strong winds of the Kaiwi Channel (Molokai Channel). Personnel of the Division of Fish and Game, Territory of Hawaii, upon the suggestion of Mr. Kenji Ego, resorted to crimping brass (bronze would probably be superior to brass) or stainless steel leader sleeve on the free ends. Such tags have held on field-tagged fish as long as six months. It would seem that corrosion of the metal would not be as serious at the ends of the nylon as it would be if it passed through the back of the fish, since the metal is not subject to stresses of bending or twisting at the former location. Nevertheless, given enough time, corrosion may result in a loosening of the metal tab from the nylon.

Tests were run to compare the strength of monofilament nylon when knotted, when a metal sleeve was crimped at the ends, and when the ends were melted into knobs. Nylon of 0.035-inch diameter (rated 60-pound test) was used. When knotted with two half hitches, the nylon broke at the knot under the stress of 24 to 26 pounds dead weight. When a one-eighth-inch length of brass leader sleeve, one-sixteenth inch in outside diameter, was strongly crimped at the ends, the nylon pulled out of the metal sleeves at forces of from 16.60 to 21.58 pounds dead weight (five trials). When the ends of a nylon filament were melted to 2-mm. knobs which were allowed to set in air, 9.08 to 11.23 pounds of dead weight caused breakage at the base of a knob (five trials). When tests of tensile strength were made on nylon with knobs which had been cooled in water immediately upon being formed by melting, the breaking occurred under a strain of about half this weight.

Although it is evident that a considerable loss of strength occurs from heating, it should be emphasized that the strength of the nylon which passes through the body of the fish and the holes in the disks is unimpaired. As long as growth pressure is not brought to bear against the disks, it is unlikely that a force of 10 pounds could be experienced against a knob on a fish which does not exceed a half pound in weight. Also, the nylon would probably tear through the flesh of a surgeon fish before such a force could be exerted. However, should greater strength be desired, heavier nylon could be used. Heavier plastic disks would then become necessary as well. A force of 17.6 pounds was sufficient to cause cracking at the hole in the center of a 0.036-inch thick cellulose acetate disk when it was supported from the peripheral one-sixteenth inch of its one-half-inch diameter surface.

Since the experimental work demonstrated no obvious fault in the method, field tagging was begun. Vernon E. Brock, Yoshio Yamaguchi, and Carl M. Nemoto of the Division of Fish and Game, Territory of Hawaii, provided valuable assistance in tagging operations.

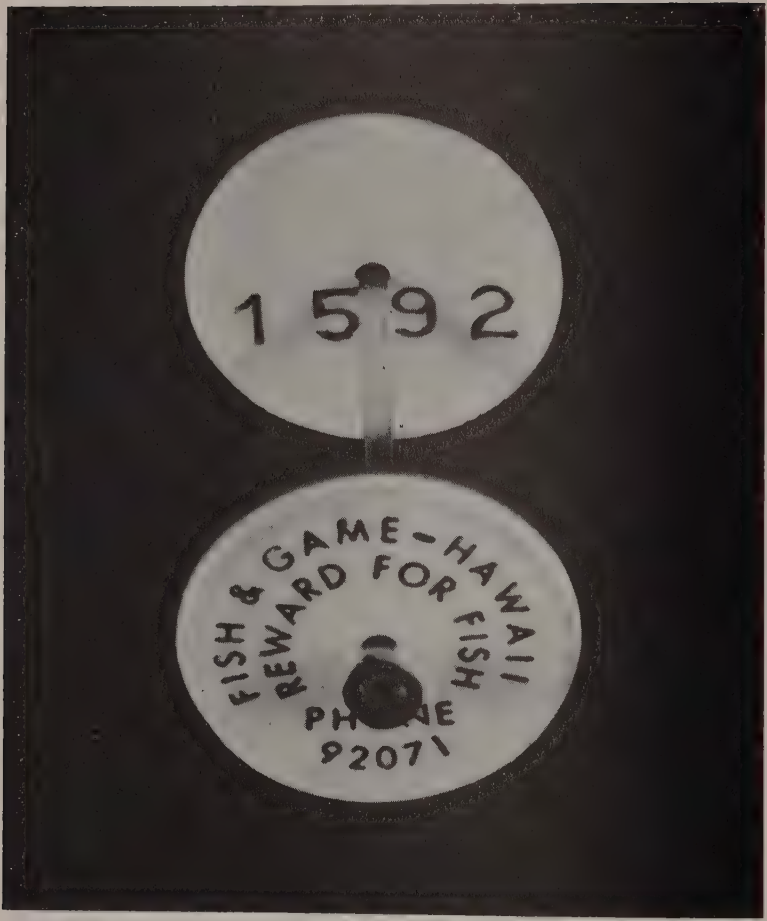

FIGURE 1. Petersen disk tag used in tagging surgeon fish in the Hawaiian Islands. The ends of the monofilament nylon connecting the two disks have been melted into knobs. The heating caused a blackening of the one knob which is visible.

The disks (Figure 1) are laminated cellulose acetate (the manufacturer much preferred to work with this material rather than cellulose nitrate because of the fire hazard associated with the latter), 0.036 inches in thickness at the center and 0.045 inches at the edge, and one-half inch in diameter. The 0.035-inch monofilament nylon fits snugly in the hole in the center of each disk. As may be noted, the tag number appears on the inside of the disks. This is advantageous, since in Hawaiian waters algae cover the outside of the tag after immersion of a month or more, but do not accumulate on the inside. Some of the algae are calcareous and difficult to remove.

Most of the fish have been tagged from commercial trapfishing vessels operating from Kewalo Basin, Honolulu. Since July 6, 1954, when extensive tagging began, a total of 1,202 manini have been tagged, and to date there have been 265 recoveries. Some fish have been recovered which had been at liberty for six and one-half months. Most of the tagged fish have been taken in traps and are brought to port alive in wells on the vessels. This has afforded an opportunity for re-release. Twenty-three tagged fish have been caught a second time, and three of these have been taken a third time.

The tagging wounds of most of the recovered fish are small, rarely exceeding 2 mm. in diameter. When the wounds are larger, the fish generally show evidence of long sojourn in traps: bacterial and fungus infections which cause eroding of the fins, and raw, abraded areas on the snout and forehead. No tags were seen in the process of migrating up through the back of the fish.

It is believed that monofilament nylon, when used without knotting, will prove to be superior to metal pins or wire for attaching Petersen disk tags to fish. Nylon appears to have the following distinct advantages over metal in general: no obvious deterioration due to corrosion or galvanic action, nontoxicity, and greater flexibility and softness.

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Feeding Habits of the Sand Crab *Hippa pacifica* (Dana)[1]

Donald C. Matthews[2]

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Feeding Habits of the Sand Crab *Hippa pacifica* (Dana)[1]

DONALD C. MATTHEWS[2]

BURROWING SAND CRABS, *Hippa pacifica* (Dana), [*Remipes pacifica* Dana of Edmondson, 1925; *Emerita pacifica* (Dana) of Edmondson, 1946, and Bonnet, 1946], were observed feeding on Portuguese man-of-war (*Physalia utriculus* Eschscholtz) at Waimanalo Beach, Oahu, during the high surf of June, 1954. However, these sand crabs completely ignored another colonial hydrozoan, *Velella pacifica* Eschscholtz, present in the surf at the time. Viewing these two colonial hydrozoans from above, astute man could easily differentiate between the gas filled float of *Physalia* and the flattened, elliptical float and oblique sail of *Velella*, but less sagacious sand crabs, viewing these colonial hydrozoans from below, could not be expected to discern subtle differences of color or length of suspended zooids. This would be especially true during a high surf because of increased turbidity, yet, in no instance did I observe even a tentative approach to *Velella*. Even though *H. pacifica* has well developed eyes, the likelihood that selection of *Physalia* and rejection of *Velella* could result solely from visual discrimination is unlikely.

Whereas unselective feeding by antennal straining has been investigated in *Emerita*, insofar as could be ascertained, no published work on selective feeding in *H. pacifica* has been reported. Therefore the experiments reported on here were performed to investigate the method by which selective feeding is accomplished.

My appreciation is extended to Dr. Maxwell Doty, University of Hawaii, for the phycological determinations and to Dr. Fenner Chace, Jr., United States National Museum, for the identification of the Hawaiian sand crabs.

METHODS AND TECHNIQUES

A. Sand crabs collected during the high surf were usually attached (singly or in groups of five or six) to their captured *Physalia*. These crabs were removed and taken immediately to the laboratory where antennae, antennules and the contents of the dissected digestive systems were examined microscopically for the presence of minute plants and animals (exclusive of bacteria), an abundance of which would indicate unselective, filter feeding.

B. *Physalia* and *Velella* disappeared from the surf as the wind subsided but, washed high on the beach, stranded colonies formed an almost unbroken line as evidence of their previous abundance in the sea. These served as a ready source of food for subsequent experiments. Sand crabs likewise disappeared from the surf as the sea calmed, leaving the wave-washed region of the beach bare. Upon this region of the beach I tossed (1) pieces of algae (*Ulva fasciata* Delile, *Turbinaria ornata* J. Agardh, *Sargassum obtusifolium* J. Agardh, *Polyopes clarionensis* Sethchell & Gardner) broken to approximately the size of *Physalia;* (2) *Velella;* (3) pieces of commercial shrimp discarded by fishermen; and (4) *Physalia*.

Sand crabs which responded to any of these materials were collected and taken to the laboratory where antennae, antennules and the contents of the dissected digestive systems were examined microscopically for evidence of filter feeding.

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C. The methods employed in B were repeated, one week later. Sand crabs collected were taken to the laboratory and the antennae, antennules and contents of the dissected digestive systems examined microscopically for evidence of filter feeding.

D. Approximately equal portions of *Ulva*, *Velella*, shrimp and *Physalia* were separately ground with sand and sea water, filtered through number 40 mesh grit gauze and each filtrate (approximately 25 cc.) diluted to 1,000 cc. of sea water. Each solution was thrown on the thin film of a receding wave and the effects, if any, noted. For each solution, a new location on the beach was chosen. Again, sand crabs which responded to any of the solutions were taken to the laboratory where antennae, antennules, and the contents of the dissected digestive systems were examined microscopically for evidence of filter feeding.

E. Twenty-five male and 25 female sand crabs were collected and their compound eyes were removed leaving the major portion of the eye stalks intact. These blinded sand crabs were placed in a small tank and allowed one day to recover from operative shock, during which time they received additional sea water. *Physalia* was again ground in sand and sea water, filtered through number 40 mesh grit gauze and the filtrate (25 cc.) diluted with approximately 1,000 cc. of sea water. The diluted filtrate, colored with 0.5 grams of neutral red was placed in a clean, 1 liter bottle fitted with four discharge pipettes. Adjustment of a single Hoffman clamp permitted the simultaneous, drop by drop, delivery of the filtrate into four paper cups (300 cc. capacity) each of which contained beach sand, sufficient to cover the bottom 2 cm., and 75 cc. of sea water, sufficient to produce a water depth of 2 cm. Four sand crabs were simultaneously tested: (1) a control male, (2) a control female, (3) a test male, and (4) a test female; each in a separate paper cup. In no case was the filtrate introduced until all four sand crabs had buried themselves in the sand. Ten drops (approximately 0.5 cc.) of filtrate were simultaneously introduced into each of the four paper cups and the reaction time recorded. This was regarded as the interval from the instant the tenth drop struck the surface of the water, to any visible response by the crab. The observed times, both for control and test animals, was averaged for five separate trials. After each experiment, paper cups and contents were discarded. These blinded sand crabs and the controls were also examined microscopically for evidence of filter feeding.

F. The methods employed in E were repeated (with fresh paper cups, sand, and sea water) except that both the compound eyes and the antennae were removed.

G. The methods employed in E were repeated, except that the compound eyes and the antennules were removed.

H. An attempt was made to test crabs with compound eyes, antennae and antennules removed. However, only 24 (of 50) sand crabs survived the severe operative shock. Of these, over half remained on their backs on the surface of the sand, displayed little or no action and were dead the following morning. The colored *Physalia* solution was introduced to the remaining 12 survivors in the small tank and the results noted. These crabs were dead on arrival at the laboratory and I regret that the contents of their digestive systems were not examined microscopically. Male and female controls were run as before (E,F,G).

RESULTS

A. Microscopic examination of sand crab antennae and antennules collected during the high surf revealed sand grains but no organisms enmeshed in the setae. The dissected digestive systems, especially the pyloric caeca, were blue, gorged with nematocysts and the shredded remains of *Physalia* zooids. There were no microorganisms nor was there any evidence, either from nematocysts or zooids, that *Velella* had been eaten.

B. As the wind subsided and *Physalia* and *Velella* no longer appeared in the surf, pieces of algae (*Ulva fasciata*, *Turbinaria ornata*, *Sargassum obtusifolium*, *Polyopes clarionensis*), *Velella* and shrimp tossed into the thin film of receding waves all failed to evoke any visible response from sand crabs but when *Physalia* was used, sand crabs emerged. Often 4 or 5 would seize a single colony simultaneously and, submerging, all take part in pulling it below. Others, often arriving at the scene too late and finding no prey, would quickly submerge as the wave receded. It was not difficult to collect 25 or more sand crabs by using a single *Physalia* colony over and over again in this manner. Microscopic examination of the antennae and antennules revealed sand grains but no organisms enmeshed in the setae. The dissected digestive systems were, as before, gorged with nematocysts and the blue remains of shredded *Physalia*, but no microorganisms were present.

C. As in B, when the waves of the calm sea broke on the beach, no crabs responded to *Ulva*. However, when *Velella*, commercial shrimp, and *Physalia* were tossed separately onto this region of the beach, crabs emerged. Microscopic examination of antennae and antennules again revealed sand grains but no organisms enmeshed in the setae. The dissected digestive systems were empty save for sand grains and what appeared to be mucus.

D. Filtered and diluted portions of ground *Ulva*, *Velella* and shrimp thrown on receding waves failed to evoke any visible response from the submerged crabs. However, when the *Physalia* filtrate was used sand crabs emerged, excitedly ran up and down the beach but, failing to locate the *Physalia*, quickly submerged. Microscopic examination of the antennae and antennules of these collected sand crabs revealed a few sand grains but no microorganisms enmeshed in the setae. Again the dissected digestive systems revealed nematocysts and the bluish remains of *Physalia* but no microorganisms.

E. Of the 50 sand crabs collected for this part of the experiment, only 18 males and 15 females survived the operative shock of eye removal. Many, even when molested, remained motionless on their backs; others righted themselves and, colliding one with another scurried around the tank. Finally, without any definite pattern of orientation, most submerged. Although the *Physalia* solution was clearly discernible as it left the four pipettes and entered the salt water of the paper cups its course became less apparent as it approached the sand so that determination of the exact moment of contact of filtrate and crabs was impossible. This condition was often further complicated by the spontaneous emerging of crabs before the first drop of filtrate could possibly have reached them. The addition of 0.5 grams of neutral red to the solution made it easy to follow the course of the filtrate. Sand crabs in all four cups emerged in great confusion during the introduction of the first six drops of filtrate. It was impossible for me to determine whether the control males and females or the blinded males and females responded more quickly. Microscopic examination of test and control crabs revealed only a few sand grains enmeshed in the setae of antennae and antennules. The digestive systems contained the remains of *Physalia* but there was no evidence of microorganisms.

F. Of the 50 sand crabs collected for this experiment, only 30 survived the operative shock of the removal of both the eyes and antennae. These exhibited about the same activities as those described in E. Again there was much confusion. Some turned over on their backs, whereas others, colliding one with another, hurried around and around the tank and finally, without special orientation, submerged. Compared to crabs having only the compound eyes removed the reaction of these crabs to the introduced filtrate was dilatory and weak. Often 3 to 5 minutes elapsed after the tenth drop of *Physalia* solution was introduced before the crabs stirred. As in E the controls emerged before the tenth drop of *Physalia* solution was introduced. Microscopic examination of the antennules of operative and control crabs revealed only sand grains enmeshed in the setae and the contents of the dissected digestive systems again revealed unaltered nematocysts but no microorganisms.

G. Of the 50 sand crabs collected for this experiment about the same number (30) survived the operative shock of removal of eyes and antennules as survived the removal of eyes and antennae. These exhibited about the same activities as those described in F. There was the same confusion, the same colliding one with another, the same running around the tank and the same submerging without any special orientation. Again 3 to 5 minutes elapsed after the tenth drop of *Physalia* solution was introduced before the crabs emerged. No difference, either in time or in magnitude of response, was discernible between blinded sand crabs with antennae removed and blinded sand crabs with antennules removed. As in E the controls emerged before the tenth drop of *Physalia* solution was introduced. Microscopic examination of the antennae of test and control crabs revealed only sand grains, and the contents of the dissected digestive systems revealed only unaltered nematocysts.

H. After the tenth drop of the colored *Physalia* solution reached the 12 sand crabs that had survived the removal of eyes, antennae and antennules 15 to 21 minutes was required before any visible response occurred. As in previous experiments the controls emerged before the tenth drop of *Physalia* solution was introduced. For the most part the test crabs merely broke the surface of the sand, appeared to "tread water" momentarily, and then settled below the surface. As previously mentioned, these crabs were dead on arrival at the laboratory and their digestive systems were not examined. No microorganisms were present on the controls.

DISCUSSION

Gregarious sand crabs lie submerged in large "beds" with only eyes and antennules projecting above the shifting, wave-washed sand. In *Emerita*, for example, exceedingly long antennae, folded behind the maxillipeds (*vide* Weymouth and Richardson, 1912, pl. 1, fig. 7), are thrust out anterolaterally as waves recede; thus characteristic **V**-shaped ripples, which mark the "bed's" location, are formed (*vide* MacGinitie and MacGinitie, 1949, figs. 145–146, p. 302). However, Hawaii's only hippid (Edmondson, 1946, p. 265), has exceedingly short antennae (*vide* Dana, 1855, Atlas: Crustacea, pl. 25, fig. 7a), thus the characteristic **V**-shaped ripples result from water striking the antennules, rather than the antennae.

Weymouth and Richardson (*op. cit.* p. 11) conclude that microorganisms found in the stomach of *Emerita analoga* were strained from waves and that antennae and mouth parts "are remarkably adapted to this form of feeding, and unfitted for any other." In *Emerita analoga* the function of sensory antennal pits in feeding appears negligible as highly diversified materials generally reported from their stomachs (diatoms, radiolarians, foraminifera, spicules, one-celled algae and sand) are "about what would be obtained by unselective straining of the water along shore" (Weymouth and Richardson, *op. cit.*, p. 9).

In contrast to the unselective antennal straining of *Emerita*, feeding by *H. pacifica*, at least during high surf, is selective as evidenced by their acceptance of *Physalia* and their rejection of algae, shrimp, and *Velella*. Moreover, this selectivity is attributed, in part at least, to some sense other than sight for, although all experimental solutions probably appeared similar to the crabs, the *Physalia* solution alone evoked visible responses. Yet, so long as the eyes remained intact, selection based on some chemical sense (*vide* Moncrieff, 1946, p. 152; Ramsay, 1952, p. 85; and Prosser *et al.*, 1950, p. 453) although a strong probability, could not be held entirely responsible for this phenomenon.

However as blinded *H. pacifica* reacted to *Physalia* solutions almost immediately, the presence of some selective chemical sense is demonstrated and, in light of similar research among other arthropods, attention was at once centered on antennae, antennules and mouth parts.

The removal of the antennae of blinded *H. pacifica* and the subsequent increase in reaction time (3–5 minutes) indicates that the chemical sense is in part located on these structures. Likewise, the removal of the antennules of blinded *H. pacifica* and the subsequent increase in reaction time (3–5 minutes) also indicates that the chemical sense is in part located on these structures. Inasmuch as the increased reaction time following the removal of the antennae so nearly approximates the increased reaction time following the removal of the antennules, one can conclude that these two structures are equally important in the degree of selectivity of the chemical sense.

To determine whether the chemoreceptors were limited to the antennae and antennules in blinded *H. pacifica*, both structures were removed. The increased reaction time (15–21 minutes) following the removal of both antennae and antennules indicates that probably there are chemoreceptors present on the still intact mouth parts, although they are much less effective than those of the antennae and antennules.

The chemoreceptors located on antennae and antennules of *H. pacifica* are therefore, responsible for the detection of *Physalia* during the high surf; the sense of sight being responsible primarily for actual location and subsequent seizure. This same chemical sense must also be responsible for detection, during calm seas, of shrimp and *Velella* which *H. pacifica* quite readily seizes once its digestive tract is empty and its preferred food scarce.

Neither the presence of shredded *Physalia* in the digestive tracts, nor the absence of minute organisms enmeshed in the setae of the antennae and antennules precludes the possibility of unselective feeding by *H. pacifica*, especially during the weeks of calm which often follow periods of heavy surf. Inasmuch as during periods of calm sand grains and mucus but no microorganisms have been found in the digestive tract of *H. pacifica* the question of unselective feeding remains unanswered.

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A Revision of the Surgeon Fish Genera *Zebrasoma* and *Paracanthurus*[1]

JOHN E. RANDALL

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A Revision of the Surgeon Fish Genera *Zebrasoma* and *Paracanthurus*[1]

JOHN E. RANDALL

THE SURGEON FISHES (Acanthuridae), like many of the families of tropical marine fishes, are in need of thorough taxonomic study on a world-wide basis. In the present paper, which is one of a series on the classification of the family (see Randall, 1955), the species of two of the genera, *Zebrasoma* and *Paracanthurus*, are considered. The question of whether *Zebrasoma flavescens* (Bennett) is or is not a dichromatic species is discussed in detail. Specimens of the three rare species of *Zebrasoma*, *Z. gemmatum* (Cuvier and Valenciennes), *Z. xanthurum* (Blyth), and *Z. rostratum* (Günther) were examined, and the validity of these species is confirmed. The postlarval *Zebrasoma* and early juvenile *Paracanthurus* are figured for the first time.

An attempt is made to give complete synonymies. Mere listings or records of species with insufficient data to permit identification are generally not included among the synonyms. When first citations are given without a locality, this information was not supplied by the author(s). A locality is listed with later citations of a species only when it appears that the author examined specimens from this locality. In the synonymies misidentifications are indicated by a period after the scientific name.

In making dorsal and anal fin ray counts, the last two rays are counted as one only when they share the same basal element. All rudiments are included in the gill raker counts. In addition to the usual counts of gill rakers (herein designated anterior gill rakers), counts of the more ridge-like rakers along the inner surface of the first gill arch (posterior gill rakers) are given.

Most of the work on this paper was done at the United States National Museum, and the author is indebted to Leonard P. Schultz, Ernest A. Lachner, and Robert H. Kanazawa for their kind assistance. All of the *Zebrasoma* and *Paracanthurus* in the collections of the Academy of Natural Sciences of Philadelphia, Museum of Comparative Zoology at Harvard College, California Academy of Sciences, Stanford Natural History Museum, Bernice P. Bishop Museum, and University of Hawaii were examined.

ZEBRASOMA Swainson

Zebrasoma Swainson (1839: 256). (Type species by monotypy, *Acanthurus velifer* Bloch.)

Body compressed, ovate, depth contained 1.4 to 2.1 times in standard length (this and other proportional measurements based on specimens over 50 mm. in standard length); head length 2.9 to 3.7 in standard length; snout produced; caudal peduncle with a single folding spine on each side, fitting into a shallow depression; length of caudal spine 3 to 6 in head length; least depth of caudal peduncle 2.7 to 3.6 in head length; mouth small, terminal; jaws equal; teeth close-set, compressed, denticulate, 10 to 20 in upper jaw, 12 to 22 in lower jaw; dorsal and anal fins elevated; dorsal fin with IV to V slender spines and 23 to 33 rays; anal fin with III spines and 19 to 26 rays; pectoral fin 2.7 to 3.3 in standard length; pectoral fin rays 14 to 17, the uppermost a short bony spicule, the next long and unbranched; pelvic fin with I spine and 5 rays, its length contained 3.5 to 4.5 in standard length; caudal fin truncate, with 16 principal rays; eye diameter (in specimens of 120 to 150 mm. in standard length) 3.5 to 4.5 in head length (except long-snouted specimens of *Z. rostratum*); interorbital slightly rounded, 2.9 to 3.4 in head length (also with the exception of *Z. rostratum*); gill openings restricted to sides; gill membranes attached to isthmus; anterior gill rakers 8 to 12; posterior gill rakers 9 to 13; scales very small, elevated, and with stout ctenii; 22 vertebrae; stomach elongate and thin-walled.

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[1] A portion of a thesis submitted to the Department of Zoology, University of Hawaii, in partial fulfillment of the requirements for the degree of Doctor of Philosophy. Contribution no. 70 of the Hawaii Marine Laboratory in cooperation with the Department of Zoology and Entomology, University of Hawaii. Manuscript received March 11, 1955.

Zebrasoma is generally considered as an Indo-West-Pacific genus. Guichenot (1853: 122), however, recorded it (as *Acanthurus scopas* Cuvier and Valenciennes) from Cuba. He mentioned the very prominent snout, the great body depth, the small rough scales, and the patch of dense setae caudally on the body. The color was noted as gray-violet with brown spots; there were lines of white marks on the side and a white band in the humeral region. His choice of words in the brief description was very similar to that of Cuvier and Valenciennes (1835: 245). No meristic data were given, but there is little question that this author was describing a *Zebrasoma*. Günther (1861: 343) considered Guichenot's citing of *scopas* from Cuba as a "most remarkable fact." L. Bertin kindly checked for the specimen in the Paris Museum for me but could find no record of it. It seems possible that Guichenot's record is an error. To my knowledge there has been no further mention of *Zebrasoma* from the Atlantic.

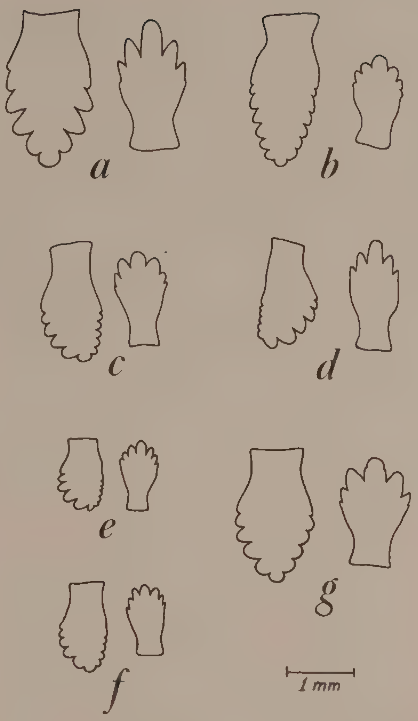


FIG. 1. Camera lucida drawings of upper and lower teeth of *Zebrasoma* and *Paracanthurus*. Teeth were taken from right side of jaws near center and drawn in inner or lingual view; the upper is to the left in each pair. *a*, *Z. veliferum*, 171 mm. specimen, Gilbert Islands; *b*, *Z. gemmatum*, 121 mm. specimen, Mauritius; *c*, *Z. xanthurum*, 181 mm. specimen, Red Sea; *d*, *Z. rostratum*, 140 mm. specimen, Tuamotu Archipelago; *e*, *Z. flavescens*, 100 mm. specimen, Johnston Island; *f*, *Z. scopas*, 108 mm. specimen, Philippine Islands; *g*, *P. hepatus*, 155 mm. specimen, Philippine Islands.

KEY TO THE SPECIES OF ZEBRASOMA

1a. Dorsal rays IV, 28 to 33; anal soft rays 22 to 26; longest dorsal ray 2.1 to 2.5 in standard length (in specimens over 50 mm. in length); body with alternate pale and dark, vertical bands . . . . **Zebrasoma veliferum**

1b. Dorsal fin rays IV or V, 23 to 28; anal soft rays 19 to 24; longest dorsal ray 2.8 to 3.7 in standard length (in specimens over 50 mm. in length); body without alternate pale and dark, vertical bands . . 2

2a. Dorsal fin rays V (rarely IV), 23 to 26; anal soft rays 19 to 22; denticulations on lateral edge of upper teeth decidedly smaller than medial denticulations (Fig. 1*c*–*f*); body and dorsal and anal fins without spots (except longitudinal lines on *scopas* broken into fine spots anteriorly on the body) 3

2b. Dorsal fin rays (based on 2 specimens) IV, 28; anal soft rays 24; denticulations on both edges of teeth of equal size (Fig. 1*b*); body and dorsal and anal fins with numerous white (said to be blue in life) spots . . . . **Zebrasoma gemmatum**

3a. Caudal fin abruptly pale (yellow in life) and in sharp contrast to dark body color; sheath of caudal spine black; profile of head from eye to upper lip only slightly concave . . . . **Zebrasoma xanthurum**

3b. Caudal fin same color as body; sheath of caudal spine white; profile of head from eye to upper lip markedly concave (as snout is strongly produced) 4

4a. Body and fins not uniform black; lower teeth with 7 denticulations, the centermost only slightly larger than adjacent ones (Fig. 1*c*, *f*) 5

4b. Body and fins uniform black; lower teeth with 5 denticulations, the centermost about twice as large as adjacent ones (Fig. 1*d*) . . . . . . **Zebrasoma rostratum**

5a. Body pale (yellow in life); dorsal soft rays 24 to 26 (usually 25); anal soft rays 19 to 22 (usually 20 or 21) . . . . **Zebrasoma flavescens**

5b. Body brown with numerous pale longitudinal lines; dorsal soft rays 23 to 25 (usually 24); anal soft rays 19 to 21 (usually 19 or 20) . . **Zebrasoma scopas**

Zebrasoma veliferum (Bloch)

Fig. 1*a*; Fig. 2; Fig. 3; Pl. 1

Acanthurus velifer Bloch (1797: 106, pl. 427, fig. 1) (seas of East Indies); Lacépède (1802: 547); Rüppell (1828: 58, pl. 15, fig. 2) (Red Sea); Cuvier (1829: 224); Cuvier and Valenciennes (1835: 251) (Mauritius, East Indies, Red Sea); Günther (1861: 344) (Fiji Islands); Playfair in Playfair and Günther (1866: 57) (Zanzibar); Klunzinger (1871: 505) (Red Sea); Day (1876: 207) (seas of India); Sauvage (1891: 344) (Madagascar).

Acanthurus Velifer Bloch and Schneider (1801: xxxviii, 214).

Acanthurus (*Harpurus*) *velifer* Klunzinger (1884: 85).

Acanthurus Desjardinii Bennett (1835: 207) (Mauritius).

Acanthurus desjardinii Günther (1861: 344) (Mauritius); Playfair in Playfair and Günther (1866: 57) (Zanzibar).

Acanthurus Ruppellii Bennett (1835: 207) (Red Sea); Bleeker (1855: 451) (Kokos Island, Sumatra).

Acanthurus rüppellii Günther (1861: 345) (Red Sea).

Acanthurus Blochii Bennett (1835: 207) (India).

Zebrasoma velifer Swainson (1839: 256); Herre (1934: 63) (Philippine Islands).

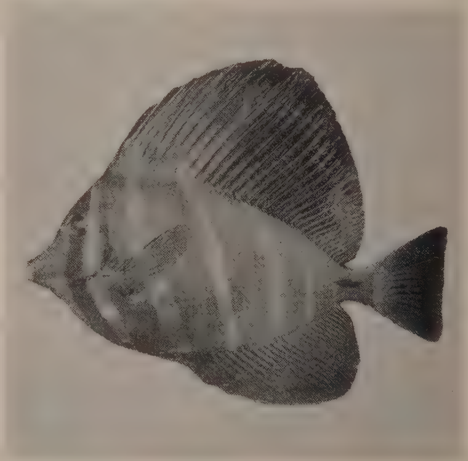


FIG. 2. *Zebrasoma veliferum* (Bloch), 183 mm., Gilbert Islands (reproduced from a 35 mm. Kodachrome transparency).

Acanthurus suillus Cuvier (1829: 224) (after Renard, 1718, vol. I, pl. 14, fig. 82); Cuvier and Valenciennes (1835: 254) (Mauritius); Günther (1861: 345).

Acanthurus élégant Liénard (1843: 69) (Mauritius) (reference from Sauvage, 1891: 344).

Acanthurus hypselopterus Bleeker (1854: 327) (Larantuka, East Indies); Günther (1861: 344); Günther (1873: 117) (Samoa, Palau Islands and Misol, East Indies).

Acanthurus maristarum Thiollière *in* Montrouzier (1856: 458) (Island of Woodlark).

Acanthurus (*Harpurus*) *hypselopterus* Steindachner (1901: 494, pl. 4, fig. 1) (Honolulu).

Acanthurus kipas Bleeker (1854: 327) (East Indies).

Harpurus hypselopterus Bleeker (1863: 252) (Flores, East Indies).

Harpurus Rüppelli Bleeker (1863: 235) (Ternate, East Indies).

Harpurus Desjardini Bleeker and Pollen (1874: 96) (Mauritius).

Acanthurus virgatus Vaillant and Sauvage (1875: 283) (Hawaiian Islands).

Acanthurus fasciatus Bliss (1883: 53) (Mauritius).

Zebrasoma hypselopterum Jenkins (1903: 479) (Honolulu); Ogilby (1916: 174, pl. 23) (Queensland, Australia).

Zebrasoma veliferum Jordan and Evermann (1905: 396, fig. 173) (Honolulu); Jordan and Seale (1906: 356) (Samoa); Kendall and Radcliffe (1912: 143) (Mangareva); Jordan and Jordan (1922: 66) (Honolulu); Herre (1927: 443, pl. 11, labelled *Zebrasoma viliferum*) (Philippine Islands); Fowler (1928: 275, pl. 32, fig. B); Fowler and Bean (1929: 255) (Philippine Islands and East Indies); Schmidt (1930: 104) (Riu Kiu Islands); Fowler (1931: 346) (Honolulu); Herre (1936: 249) (Solomon Islands); Hiyama (1943: 95, pl. 21, fig. 58); Aoyagi (1943: 205, pl. 4, fig. 6, teeth only) (Riu Kiu Islands); Schultz (1943: 166) (Phoenix Islands and Samoa Islands); de Beaufort (1951: 167, fig. 28) (New Guinea and Ambon, East Indies); Schultz and Woods *in* Schultz, *et al.* (1953: 640) (Marshall Islands); Harry (1953: 152) (Raroia, Tuamotu Archipelago).

Zebrasoma veliforum novae caledoniae Borodin (1932: 88) (New Caledonia).

Hepatus coccinatus von Bonde (1934: 449, fig. 3) (Zanzibar).

Zebrasoma velifera Marshall (1950: 195) (Cocos-Keeling Islands).

Dorsal rays IV, 28 to 33 (in Oceania usually 31 or 32); anal rays III, 22 to 26 (in Oceania usually 24 or 25); pectoral rays 15 to 17 (usually 16); anterior gill rakers 8 to 11 and posterior gill rakers 9 or 10 (12 specimens from nine localities over the range of the species); the number of teeth increase slowly with age: a 25 mm. specimen from the Gilbert Islands had 10 upper and 12 lower teeth; 51, 80, and 94 mm. specimens had 12 upper and 14 lower teeth; 128, 154, and 168 mm. specimens had 14 upper and 16 lower teeth; 233 and 245 mm. specimens had 16 upper and 18 lower teeth.

Dorsal fin very elevated, longest soft dorsal ray 2.1 to 2.5 in standard length; fourth dorsal spine 2.5 to 2.8 in standard length; body depth 1.8 to 2 in standard length (1.4 in 25 mm. specimen); no patch of stiff bristles on side of body anterior to caudal spine. The posterior end of the caudal spine is not as broadly joined to the body in *veliferum* as in other species of *Zebrasoma*.

Color (in alcohol) brown with alternate, near-vertical, dark and light (pale yellow in life) bands; the first dark band passes through the eye and angles backward to the origin of the pelvic fins; the first pale band runs from the nape across the opercle just behind the eye to the pelvic region; the remaining four or five pale bands on the body are about one-third to one-fourth as broad as the intermediate brown areas, and each is bissected by a narrow dark line; within the intermediate brown areas alternate lines of dark and light are perceptible, the dark lines tending to

TABLE 1
FIN RAY COUNTS OF SPECIMENS OF SPECIES OF *Zebrasoma* FROM VARIOUS LOCALITIES

SPECIES AND LOCALITY	DORSAL SPINES		DORSAL SOFT RAYS											ANAL SOFT RAYS								PECTORAL RAYS			
	IV	V	23	24	25	26	27	28	29	30	31	32	33	19	20	21	22	23	24	25	26	14	15	16	17
veliferum																									
Hawaiian Is.	11									3	4	4							3	7	1		1	9	1
Phoenix Is.	3										1	2								2	1			3	
Samoa Is.	3											3								2	1			3	
Marshall Is.	6										3	3							2	4			1	5	
Gilbert Is.	10										4	4	2						4	5	1		3	7	
Society Is.	4								1		2	1							1	3				4	
Mangareva	1										1									1				1	
Philippine Is.	24									5	8	11						2	5	17			9	15	
East Indies	3										1	2								2	1			3	
Mauritius	8						1	6	1								1	6	1					8	
Zanzibar	1							1										1						1	
Egypt, Red Sea	7							2	3	1	1						2	4	1				1	5	1
gemmatum																									
Mauritius	2							2											2					1	1
xanthurum																									
Egypt, Red Sea		7		6	1									4	3								7		
rostratum																									
Tuamotu Arch.	1	10	1	7	3									1	10								11		
Society Is.		2		2											2								2		
flavescens																									
Hawaiian Is.	2	56	1	13	32	12								2	19	34	3					1	54	3	
Johnston I.		5		2	3										2	3							4	1	
Wake I.		3			3										1	2							2	1	
N. Marshall Is.		1				1										1							1		
Marcus I.		1			1											1							1		
Mariana Is.		6		1	2	3										5	1						4	2	
scopas																									
N. Marshall Is.	1	7		6	2										7	1							8		
Gilbert Is.		3	1	2										1	2								3		
Samoa Is.		21	1	14	6									4	15	2						2	18	1	
Society Is.		14	1	8	5									2	11	1						3	10	1	
Riu Kiu Is.		1	1											1									1		
Philippine Is.	1	41	9	28	5									10	32							7	33	2	
East Indies		13	2	9	2									2	11							1	12		
Mauritius		4		3	1										4								4		

break into spots antero-ventrally on the body; head and chest with small pale spots; dorsal and anal fins dark with curved pale lines which may be broken into spots; caudal fin dark with faint pale spots; caudal spine in a blackish area.

The low dorsal and anal fin ray counts (Table 1) of the Red Sea, Zanzibar, and Mauritius specimens and slightly different color (the very narrow vertical pale lines on the body are more conspicuous) suggest that the form in the Indian Ocean and Red Sea might be regarded as a different subspecies from that in the East Indies and Oceania. Many more specimens from various parts of the Indian Ocean are needed to establish the nature of subspecific differentiation in this species.

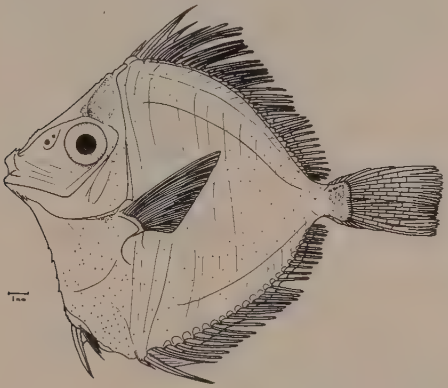


FIG. 3. Postlarval *Zebrasoma veliferum*, 18 mm., Hawaiian Islands. Drawn with the aid of a camera lucida by H. Randall.

The 18 mm. postlarval specimen of *Z. veliferum* (Fig. 3) was collected by Joseph E. King of the Pacific Oceanic Fishery Investigations on Dec. 26, 1951 offshore from Kaneohe, Oahu. It was taken in an oblique haul from the surface to about 200 meters with a 6 foot trawl.

The juvenile specimen (Pl. 1) was taken with rotenone by the author from a channel of 3 to 5 foot depth at Onotoa Atoll, Gilbert Islands. The area was sandy with occasional heads of *Heliopora*.

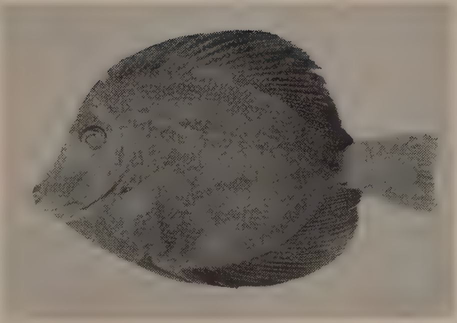


FIG. 4. *Zebrasoma gemmatum* (Cuvier and Valenciennes), 121 mm., Mauritius.

The largest specimen seen by me was 275 mm. in standard length. De Beaufort (1951: 169) recorded total length to 395 mm., which would be about 315 mm. in standard length.

Although widespread in the tropical Indian and West Pacific Oceans, this species is not as abundant as many of the other surgeon fishes. Schultz and Woods (1953: 641) state that a large school was observed entering shallow water in the Marshall Islands; the individuals of the school were swimming at times with their dorsal fins out of water like a sail. I have occasionally observed *Z. veliferum* underwater in the Hawaiian Islands and in the Gilbert Islands, but only as solitary individuals. I have never seen the dorsal fin elevated.

Zebrasoma gemmatum
(Cuvier and Valenciennes)
Fig. 1*b;* Fig. 4

Acanthurus gemmatus Cuvier and Valenciennes (1835: 255) (Mauritius); Günther (1861: 343); Sauvage (1891: 343) (Madagascar?).

Harpurus gemmatus Bleeker and Pollen (1874: 96) (Mauritius).

Zebrasoma gemmatum Fowler and Bean (1929: 258).

Dorsal rays IV, 28; anal rays III, 24; pectoral rays 16 or 17; anterior gill rakers 12 and posterior gill rakers 11; 121 mm. specimen with 15 upper and 17 lower teeth; 179 mm. specimen with 18 upper and 20 lower teeth.

Longest soft dorsal ray 3 to 3.1 in standard length; fourth dorsal spine 4.5 to 5.9 in standard length; body depth 1.7 to 1.9 in standard length; no patch of setae on side of body anterior to caudal spine. All counts and measurements are based on two specimens.

Color (in alcohol) brown with numerous white spots on head, body, dorsal and anal fins, base of pectoral fin, and very faintly on caudal fin (these spots tend to be round on fins, head, and dorsal part of body, but elongate elsewhere on the body); caudal fin pale.

Cuvier and Valenciennes (1835: 256) stated that the caudal fin was yellow. Sauvage (1891: 344) (after Liénard) described the spots on this fish as blue.

Z. gemmatum is known only from the island of Mauritius and possibly Madagascar.

Zebrasoma xanthurum (Blyth)

Fig. 1*c;* Fig. 5

Acanthurus xanthurus Blyth in Kelaart (1852: appendix p. 50) (Ceylon); Günther (1861: 343); Playfair *in* Playfair and Günther (1866: 57, pl. 8, fig. 4) (Aden); Klunzinger (1871: 504) (Red Sea); Day (1876: 207).

Acanthurus (*Harpurus*) *xanthurus* Klunzinger (1884: 85).

Zebrasoma xanthurum Fowler and Bean (1929: 262).

Dorsal rays V, 24 or 25; anal rays III, 19 or 20; pectoral rays 15; gill rakers (from one specimen): anterior 11, posterior 13; upper teeth 18 to 20; lower teeth 22.

Longest soft dorsal ray 3.4 to 3.7 in standard length; fifth dorsal spine 3.9 to 4.1 in standard length; body depth 1.7 to 1.85 in standard length; an oval, velvety patch on side of body anterior to caudal spine. All measurement and meristic data except gill raker counts based on seven specimens, 120 to 181 mm. from the Red Sea.

Color (in alcohol) dark gray to black with small spots on head, nape, and chest (these spots pale on two of the specimens and dark on the others); entire caudal fin abruptly yellowish white just posterior to caudal spine; dorsal, anal, and pelvic fins dark gray; pectoral fin with basal two-thirds dark gray, outer one-third pale.

Blyth (in Kelaart, 1882: appendix p. 50) described the color in life from a 7.5 inch specimen as ". . . wholly black with bright golden-yellow tail, and a tinge of the same upon the pectorals."

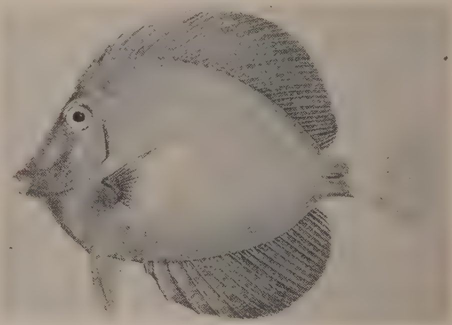


FIG. 5. *Zebrasoma xanthurum* (Blyth), (after Playfair, 1866).

This species is difficult to separate from *Z. scopas* and *Z. flavescens* on any basis other than color. The snout is slightly less produced in *Z. xanthurum* and, for a comparable size, the velvet like area on the side much less developed. It seems likely that *Z. xanthurum* attains a larger size. Four of the seven specimens from the Red Sea range from 145 to 181 mm. in standard length. The largest *Z. scopas* I have seen is 149 mm. in standard length (from the Society Islands). Of over 100 adult specimens in the United States National Museum from the Philippines and East Indies, the largest is 145 mm. and only nine exceed 115 mm. The largest of many *Z. flavescens* examined by me is a Hawaiian specimen 149 mm. in length.

Zebrasoma xanthurum is thus far reported only from Ceylon, the Gulf of Aden, and the Red Sea.

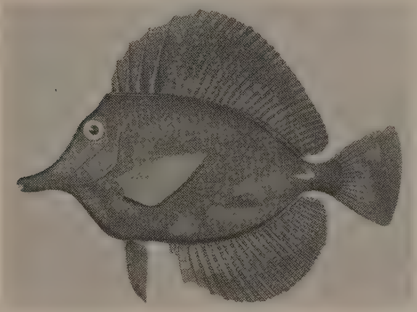


FIG. 6. *Zebrasoma rostratum* (Günther), (after Günther, 1873).

Zebrasoma rostratum (Günther)
Fig. 1*d;* Fig. 6

Acanthurus rostratus Günther (1873: 117, pl. 66, fig. B) (Society Islands).

Zebrasoma rostratum Fowler (1928: 275); Harry (1953: 152) (Raroia, Tuamotu Archipelago).

Zebrasoma (*Laephichthys*) *rostratum* Fowler and Bean (1929: 262).

Laephichthys rostratus Fowler (1938: 127) (Apataki, Tuamotu Archipelago); Fowler (1952: 25, fig.).

Dorsal rays V (rarely IV), 23 to 25; anal rays III, 19 or 20; pectoral rays 15; anterior gill rakers 10 and posterior gill rakers 9 or 10 (from 2 specimens, Society Islands); 84 and 121 mm. specimens had 16 upper and lower teeth; a 166 mm. specimen had 16 upper and 18 lower teeth, and a 170 mm. specimen 18 upper and lower teeth.

Longest soft dorsal ray 3 to 3.7 in standard length; fifth dorsal spine 3.7 to 4 in standard length; body depth about 2 in standard length; patch of setae in front of the caudal spine may or may not be present (two of seven specimens which could be sexed had well-developed setae and were males; the others lacked this bristle area and were females; thus it is possible that this is a sexual character in this species).

The long snout was believed to be the most characteristic feature; however, examination of a series of 10 specimens in the Stanford Natural History Museum, collected by R. R. Harry from Raroia Atoll in the Tuamotus, revealed considerable variability in snout length. The ratio of snout length (measured from tip of upper teeth to nearest edge of eye) to standard length (tip of snout to base of caudal fin) ranged from about 3 to 5. This variability is not associated with growth nor does it appear to be related to sex.

I did not observe the dorsal spines to be noticeably stouter than those of other species of *Zebrasoma*, although Garrett's drawing (in Günther, 1873, reproduced herein as Fig. 6) shows them to be.

Color (in alcohol) entirely black except membranes of pectoral fin which are clear, the caudal spine which is hyaline with a white sheath, and in some specimens a faint pale longitudinal band in the posterior half of the dorsal and anal fins. Harry (1953: 152) gives the life color as solid black with white caudal spine.

Günther described *Acanthurus rostratus* from Garrett's notes and his painting of a 7.5 inch specimen. It has been presumed that the specimen is not in existence; however, I found two collected by Garrett, both 7.5 inches in total length, at the Museum of Comparative Zoology. It seems likely that one of these was the basis for the figure and therefore should be considered as the type.

Fowler (1938: 128) thought that the velvety patch in front of the caudal spine was removed by the publishers of "Fische der Südsee" from the painting. In this he is probably in error, for both of the Garrett specimens are females and lack this setous area.

Zebrasoma rostratum is known only from the Society Islands and two islands in the Tuamotus. Harry collected his specimens from lagoon shore reefs at Raroia and observed the species also on lagoon coral heads.

Zebrasoma flavescens (Bennett)
Fig. 1*e;* Fig. 7

Acanthurus flavescens Bennett (1828: 41) (Oahu); Günther (1873: 116, pl. 76, fig. B) (Hawaiian Islands); Steindachner (1901: 493) (Honolulu).

Zabrasoma agaña Seale (1901: 110) (Guam).

Zebrasoma flavescens Bryan and Herre (1903: 134) (Marcus Island); Jordan and Evermann (1905: 397, pl. 59) (Oahu); Jordan and Seale (1906: 355); Jordan and Jordan (1922: 66) (Hawaii); Fowler and Ball (1925: 19) (Johnston Island); Fowler (1928: 274, pl. 32, fig. A) (Hawaiian Islands, Johnston Island, Marcus Island); Aoyagi (in part) (1943: 203) (Riu Kiu Islands); Schultz and Woods *in* Schultz *et al.* (in part) (1953: 641) (Bikini Atoll, Marshall Islands).

Scopas flavescens Jenkins (1903: 480) (Honolulu and Puako Bay, Hawaii).

Dorsal rays V (rarely IV), 23 to 26 (usually 24 or 25); anal rays III, 19 to 22 (usually 20 or 21); pectoral rays 14 to 16 (usually 15); anterior gill rakers 8 to 12 and posterior gill rakers 11 or 12 (based on a total of 12 specimens from the Hawaiian Islands, Johnston Island, Wake Island, Bikini Atoll, Marcus Island, and Guam); a 25 mm. transforming specimen from Saipan had 12 upper and 14 lower teeth; a 77 mm. specimen collected by Schultz, Hiatt, and Brock at Bikini (U.S.N.M. No. 140586) had 15 upper teeth and 18 lower teeth; a 149 mm. specimen from Hawaii had 18 upper and 22 lower teeth.

The following proportional measurements were made on 15 specimens from 75 to 149 mm. in standard length: length of longest dorsal ray 2.8 to 3.8 in standard length; length of fifth dorsal spine 2.95 to 4.0 in standard length; body depth 1.4 to 1.75 (2.4 in 26 mm. juvenile specimen); a well-developed dense patch of setae posteriorly on the side of the body, progressively more prominent in larger specimens.

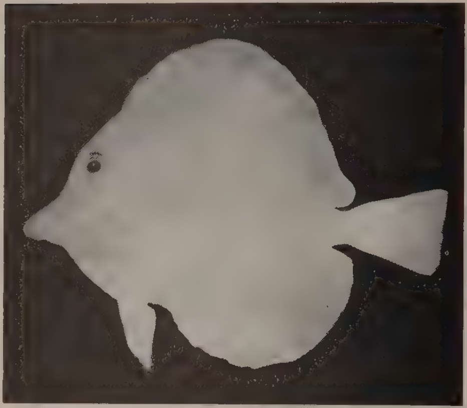


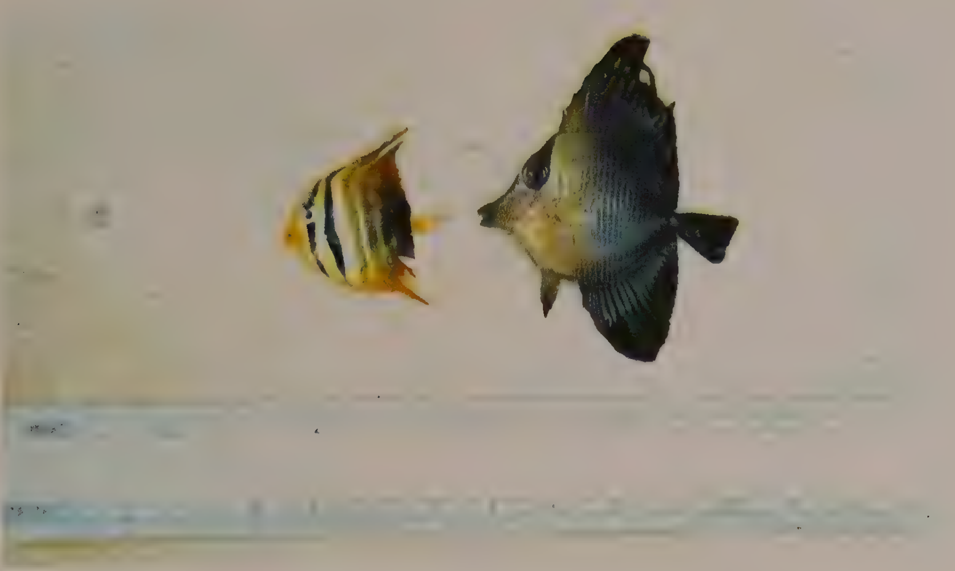
FIG. 7. *Zebrasoma flavescens* (Bennett), 120 mm., Hawaiian Islands (reproduced from a 35 mm. Kodachrome transparency).

Color (in alcohol) uniform yellowish white, in life bright chrome yellow. Upper edge of pectoral fin with a very narrow dark margin; sheath of caudal spine white. Preserved specimens often show a long, faint whitish pale band running backward and slightly downward from just behind the upper end of the gill opening.

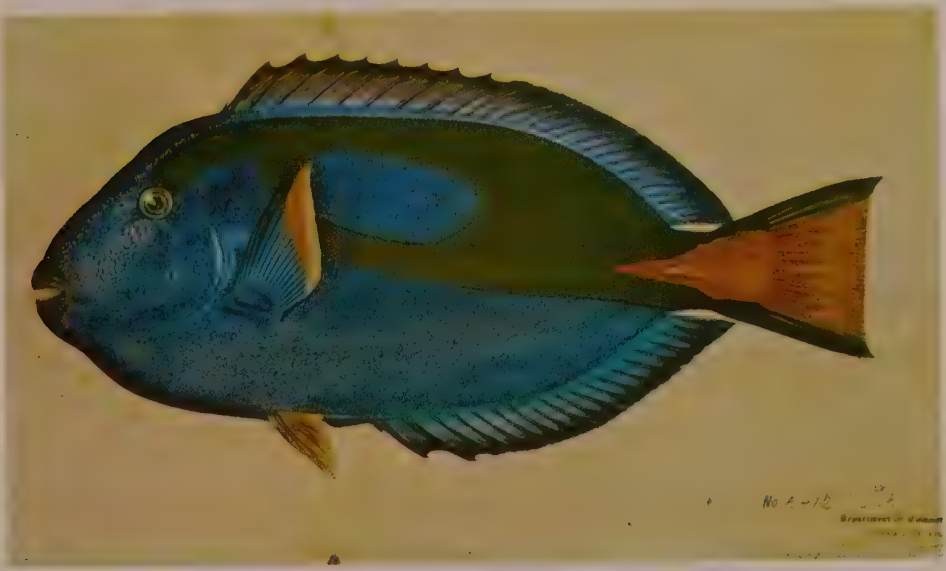
Two of three yellow specimens of *Z. flavescens* (U.S.N.M. No. 140567) collected by L. P. Schultz from Johnston Island are a light dusky color over the back and head and there is a slight concentration of brownish pigment anteriorly in the dorsal fin. The yellow Bikini specimen shows this same diffuse marking in the fin. Still, this is but a slight departure from the usual pure yellow color.

This brightly-colored species is abundant in the Hawaiian Islands. Brock (1954: 302) calls attention to the interesting fact that it is much more common on leeward sides of islands than windward. His figure 1 shows the relative abundance of this fish (as *Zebrasoma*) in nine different localities around the islands of Hawaii and Oahu.

Jordan and Evermann (1905: 398) believed *Acanthurus virgatus* Vaillant and Sauvage to be the young of *Z. flavescens* and placed it in the synonymy of the latter. *A. virgatus* had vertical dark bars on the body and was probably a juvenile *Zebrasoma veliferum*. Juvenile



Young of *Zebrasoma veliferum* (left) and *Z. scopas,* Gilbert Islands (from a Kodachrome by the author).



Paracanthurus hepatus, 204 mm., Philippine Islands (from an unpublished painting in the files of the U. S. Natl. Mus.).

Z. flavescens display no dark markings of any kind. A 21.5 mm. transforming specimen taken at a depth of 40 feet off Waikiki, Oahu, on June 3, 1952 was bright yellow in color like adults.

Except for one sight record in the Tuamotus (Harry, 1953), *Z. flavescens* appears to be confined to the northern part of the tropical Pacific. I have seen specimens only from the Hawaiian Islands, Johnston Island, Wake Island, Marcus Island, northern Marshall Islands, and the Marianas (including the type of *Z. agaña* Seale from Guam, kindly loaned by E. H. Bryan of the Bishop Museum, and two small bright yellow specimens collected by Eugenie Clark at Saipan). See section on *Z. scopas* for further discussion of *Z. flavescens.*

Zebrasoma scopas (Cuvier)

Fig. 1*f*; Pl. 1

Acanthurus scopas Cuvier (1829: 224) (after Renard, 1718, vol. 1, pl. 40, fig. 210) (Neira, Province of Banda); Cuvier and Valenciennes (1835: 245, pl. 290) (New Guinea); Bleeker (1851: 348) (Solor, East Indies); Thiollière *in* Montrouzier (1856: 459) (Island of Woodlark).

Acanthurus rhombeus von Kittlitz (1834: 194, pl. 13, fig. 6) (Ulea Island = Woleai Atoll, Caroline Islands); Günther (1861: 342) (Aneityum, New Hebrides and Ceram, East Indies); Playfair *in* Playfair and Günther (1866: 57) (Zanzibar).

Acanthurus altivelis Cuvier and Valenciennes (1835: 249) (Indian Ocean and Mauritius).

Harpurus scopas Swainson (1839: 256).

Acanthurus goramensis Bleeker (1858: 208) (Goram, East Indies); Günther (1861: 343); Jatzow and Lenz (1898: 514, pl. 36, fig. 11) (Zanzibar).

Harpurus rhombeus Bleeker (1863: 271) (Timor, East Indies).

Acanthurus flavescens. Günther (1873: 116, pl. 76, fig. A) (Tahiti); Sauvage (1891: 342) (Madagascar).

Zebrasoma rhombeum Jordan and Seale (1906: 355) (Samoa); Jordan and Seale (1907: 34) (Panay, Philippine Islands); Jordan and Richardson (1908: 270) (Cagayancillo, Philippine Islands); Fowler (1928: 275) (Indo-Pacific, but not Hawaiian Islands, Johnston Island, or Marcus Island).

Zebrasoma flavescens. Jordan and Fowler (1902: 555) (Okinawa); Herre (1927: 441) (Philippine Islands); Fowler and Bean (1929: 258) (Philippine Islands and East Indies); Schmidt (1930: 103) (Riu Kiu Islands); Giltay (1933: 86) (East Indies); Herre (1934: 63) (Philippine Islands); Herre (1936: 248) (Society Islands, New Hebrides, Solomon Islands); Poll (1942: 11, fig. 3) (Tahiti); Aoyagi (in part) (1943: 203, pl. 8, fig. 3) (Riu Kiu Islands); Schultz (1943: 167) (Samoa Islands); de Beaufort (1951: 170) (Java); Schultz and Woods *in* Schultz *et al.* (in part) (1953: 641, pl. 66, fig. B) (Marshall Islands); Harry (1953: 152) (Raroia, Tuamotu Archipelago).

Zebrasoma rostratum. Jordan and Seale (1906: 356) (Samoa).

Zebrasoma supra-alba Fowler (1946: 198, fig. 70) (Riu Kiu Islands).

Dorsal rays V (rarely IV), 23 to 25 (usually 24); anal rays III, 19 to 21 (usually 19 or 20); pectoral rays 14 to 16 (usually 15); anterior gill rakers 9 to 12 and posterior gill rakers 10 to 13 (based on a total of 12 specimens from the Marshall Islands, Samoa, Society Islands, Philippine Islands, and East Indies); a 30 mm. specimen from the Gilbert Islands had 12 upper and 14 lower teeth; a 74 mm. specimen from the Philippines had 14 upper and 16 lower teeth; a 145 mm. specimen from the Philippines had 18 upper and 22 lower teeth.

The following proportional measurements were made on 15 specimens from 52 to 145 mm. in standard length: length of longest dorsal ray 2.7 to 3.6 in standard length; length of fifth dorsal spine 2.9 to 3.9 in standard length; body depth 1.5 to 1.7 in standard length (2.2 in a 30 mm. juvenile); oval-shaped brush-like patch of setae on sides, very prominent in larger specimens where it extends nearly half way to the base of the pectoral fin from the caudal spine (this velvet-like region first becomes apparent in specimens of 65 to 70 mm. in standard length).

Color (in alcohol) brown with numerous, thin, light gray, irregular, horizontal lines on the body which are broken into discrete spots anteriorly and on head; on small specimens (about 45 to 65 mm. in length) the lines are entirely broken up on the body. Specimens smaller than 45 mm. have narrow vertical pale lines on the body between which spots are aligned vertically. In most specimens, regardless of length, a dusky white band of about the diameter of a pupil of eye in width extends posteriorly from a point just behind the upper edge of the gill opening over half the distance to the caudal spine. Sheath of caudal spine white; median fins brown; pectoral fin membranes hyaline, rays light brown; upper edge of unbranched pectoral ray with a narrow black line.

Color (in life) dark brown, yellowish brown anteriorly, with numerous, narrow, wavy, light blue longitudinal lines on the body, breaking up to small blue dots on nape, chest, and head (no linear pattern being evident on the latter); all fins except pectorals dark brown; pectorals clear with dusky orange rays and a narrow black upper margin. This color note was obtained from an 88 mm. specimen collected by me from a recess in a stand of dead staghorn coral in the lagoon of Onotoa Atoll, Gilbert Islands.

Although colors of olive or dark green and black have been given for the species, the majority of the records of the basic life color are brown. The other colors may represent variability which is possible in individual specimens. Other acanthurids are known for the ability to alter their hues (Townsend, 1929). *Ctenochaetus striatus* (Quoy and Gaimard), also a brown, blue-lined species, may appear almost black or distinctly olivaceous when alive.

The young of *Z. scopas* and *Z. veliferum* are compared in the upper figure of Plate 1. The photograph is of fresh specimens captured at Onotoa Atoll.

Schultz and Woods (1953: 642) reported that this species was found in or close to deep water in the Marshall Islands. I observed adults in about 8 feet of water in the Onotoa lagoon and on the lee reef of Butaritari Atoll in the Gilbert Islands; however, they were seen infrequently.

The largest specimen in the museum material which I have examined measured 149 mm. in standard length.

Varied opinions as to the relationship of *Z. scopas* and *flavescens* have been expressed in the literature.

Günther (1873: 117) united *Acanthurus rhombeus* (= *Z. scopas*) with *flavescens*, regarding the yellow form in Hawaii as probably a case of albinism. Jordan and Seale (1906: 355) (1907: 34) stated that the two are probably the same species, though they retained both names. Herre (1927: 443), Fowler and Bean (1929: 260), Aoyagi (1943: 204), Schultz and Woods (1953: 152), and others have asserted their belief that these are color forms of a single species. Jordan and Fowler (1902: 556) wrote, "Probably the typical *flavescens* is found in deep water, the variety *rhombeum* living near shore." Certainly this does not seem to be true, for neither form appears restricted to any particular depth on the reef. I have observed *Z. flavescens* in Hawaii in from about 3 to 90 feet of water. *Z. scopas* (as here defined) is known from Zanzibar to southern and western Oceania. In spite of extensive collecting and underwater observation in the Hawaiian Islands, Johnston Island, and Wake Island by W. A. Gosline, V. E. Brock, myself, and others, no specimens of *Z. scopas* (the so called brown phase of *Z. flavescens*) have been seen, although the bright yellow *Z. flavescens* is abundant. The few museum specimens from Marcus Island and Guam are pale, presumably yellow in life, and hence *Z. flavescens*.

I have examined 167 specimens from the Philippines, East Indies, Gilbert Islands, Samoa Islands, Society Islands, and Mauritius, and all were brown. Jordan and Seale (1906: 356) had 50 specimens from Samoa and saw none yellow in color. Fowler (1928: 274) recorded *Z. flavescens* from the Hawaiian Islands, Johnston Island, Samoa, Marcus Island, and Raiatea and described the species from preserved specimens as fuscous-black with fine grayish lines. Of his specimens only those from Samoa and Raiatea were of this color; the rest were pale yellowish.

Only from Bikini Atoll in the northern Marshall Islands have I seen both yellow and brown specimens from the same area. Of 14 specimens only one was yellow. Aoyagi (1943: 204) reported both yellow and brown and intermediate forms from the Riu Kiu Islands, however, he mentioned that there was some geographical separation. R. R. Harry (1953: 152) stated that he observed one yellow specimen underwater at Raroia Atoll in the Tuamotus but took only the dark form. Upon discussing this sight record with Harry, I learned that he was unaware of the solid bright yellow color of the young of *Acanthurus olivaceus* Bloch and Schneider. He than stated that he could not be certain that the specimen he saw was *Z. flavescens* and not *A. olivaceus*.

My efforts to distinguish the yellow *Z. flavescens* and the brown *Z. scopas* on other grounds than color met with the usual failure except for fin ray counts (Table 1) which provide a partial separation, the counts of *Z. flavescens* being higher. One might say that this meristic difference is due to the colder water of the northern part of Oceania to which the yellow "phase" seems to be restricted. However, the water of the Mariana Islands is as warm as the warmest areas of the Pacific (more specimens are needed from this region however, to be certain that the fin ray counts are really higher), and the fin ray counts of *Z. scopas* from the Society Islands, which are about as far south as the Hawaiian Islands are north and have sea surface temperatures which are almost as cool as Hawaii (Hydrographic Office, 1944), show no increase (Table 1). Also *Z. veliferum* does not exhibit any obvious increase in ray counts in the Hawaiian Islands.

In view of the available data, I do not believe that *Z. flavescens* and *Z. scopas* can be considered as color varieties of one polymorphic species. If they were color varieties, at least an occasional brown specimen should have turned up in areas like the Hawaiian Islands, or yellow ones from the southern or western tropical Pacific or Indian Oceans. More important, one would not expect the fin ray counts of both phases to be different. Two other possibilities exist: the brown and yellow forms are full species or they are subspecies. My data are not yet sufficient to decide with assurance which is the case. At the present time I favor considering the two as species, although I may be placing too much emphasis on the single yellow specimen from Bikini with higher fin ray counts than brown specimens from the same atoll. This one yellow specimen might have been carried there as a larva from a *Z. flavescens* area such as Wake Island. If this were true, the case for subspecies would be strengthened.

The claim made by Aoyagi that yellow, brown, and intermediate forms occur in the Riu Kius is difficult to assess and should be checked. The intermediate forms were described as yellowish brown with minute spots. This is normal coloration for subadult and juvenile *Z. scopas*; thus this author might not have observed true intermediate forms at all. If the "geographical separation" which he mentioned is north-south within this island chain and true intermediate forms were found in a region of contact of the yellow and brown, the best explanation would be in terms of subspecies.

I examined the type of *Zebrasoma supra-alba* Fowler from the Riu Kiu Islands at the Academy of Natural Sciences of Philadelphia. The unique feature of the anterior part of the dorsal fin being white appears to be caused by damage to the specimen. The fin membranes of the first four spines are completely torn off. A white area does appear posterior to the fourth spine to about the middle of the fin, but this seems to be due to a stripping off of the pigmented epidermis. The fin ray counts of this specimen are given in Table 1 for the Riu Kiu Islands under the heading *scopas*.

PARACANTHURUS Bleeker

Paracanthurus Bleeker (1863: 252). (Type species, *Acanthurus hepatus* (Linnaeus) Bloch and Schneider = *Teuthis hepatus* Linnaeus as restricted by Cuvier and Valenciennes.) The characteristics of the genus are those of the single known species.

Paracanthurus hepatus (Linnaeus)

Fig. 1*g;* Fig. 8; Pl. 3

Teuthis hepatus Linnaeus (in part) (1766: 507) (after Seba, 1734, and Valentijn, 1724) (sea of the Indies).

Acanthurus hepatus Bloch and Schneider (in part) (1802: 11); Cuvier and Valenciennes (1835: 183, pl. 288) (Mauritius and New Guinea); Bleeker (1854: 325) (Flores, East Indies); Günther (1861: 341) (Ambon, East Indies); Günther (1873: 115, pl. 75) (Gilbert Islands); Day (1876: 206) (seas of India).

Acanthurus theuthis Lacépède (1802: 547, 549).

Acanthurus Theuthis Shaw (1802: 377).

Acanthurus triangulus Cuvier and Valenciennes (1835: 189) (after Vlaming); Günther (1861: 341).

Paracanthurus hepatus Bleeker (1863: 252) (Ceram, East Indies); de Beaufort (1951: 131, fig. 25) (Pulu Weh and Banda, East Indies).

Colocopus lambdurus Gill (1885: 279); Jordan and Seale (1906: 355).

Acanthurus teuthis Weber (1913: 318) (Banda, East Indies).

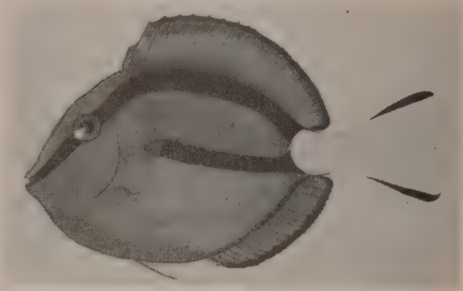


FIG. 8. *Paracanthurus hepatus* (Linnaeus), 30 mm., Schouten Islands, East Indies (photograph of an unpublished painting by Frederick M. Bayer).

Paracanthurus lambdurus Fowler (1926: 140); Herre (1927: 435, pl. 13, fig. 3) (Philippine Islands); Herre (1934: 63).

Paracanthurus theuthis Fowler (1928: 273); Fowler and Bean (1929: 205, fig. 10) (Philippine Islands and East Indies); Fowler (1931: 344) (Palau Islands); Aoyagi (1943: 202, pl. 8, fig. 1, pl. 4, fig. 8) (Riu Kiu Islands); Smith (1949: 239, pl. 33, no. 607) (Mozambique).

The following is based on the one catalogued adult specimen in the United States National Museum (No. 146636, 204 mm., Philippine Islands): body compressed, elliptical, the depth contained 2.3 in standard length; head length contained 3.75 in standard length; a broad groove on each side of caudal peduncle with a single movable spine, sharp anteriorly, broadly joined to body posteriorly; length of caudal spine 4 in head length; least depth of caudal peduncle 2.4 in head length; mouth very small, terminal; jaws equal; teeth small, close-set, denticulated, 14 in upper jaw and 17 in lower jaw (a 140 mm. specimen from the Gilbert Islands and now in the Bishop Museum, Honolulu, had 12 upper and 14 lower teeth); all spines of fins stout; dorsal and anal fins not elevated, longest dorsal ray 8.2 in standard length; dorsal fin rays IX (the first very short), 19 or 20; anal fin rays III (the first very short), 18 or

19 (based on four specimens from the Philippines, one from the Gilbert Islands, and two from Mauritius); pectoral fin rays 16; pelvic fin rays I, 3 (the first soft ray closely applied to the spine); length of pectoral fin 4.3 in standard length; length of pelvic fin 7.5 in standard length; caudal fin with 16 principal rays, truncate with upper and lower lobes slightly projecting; length of caudal fin 5.6 in standard length; eye small, 6 in head length; interorbital highly arched, 3.4 in head length; gill openings well-restricted to sides; gill membranes confluent and very broadly attached to isthmus; scales of body thick, each with many short ctenii on upper surface (ctenii on scales in a small area just anterior to caudal spine about three times as long as elsewhere on body); scales on head, especially anteriorly, enlarged to tuberculated plates; 22 vertebrae; stomach oval with moderately thick walls.

Color (in alcohol) light grayish brown (blue in life) with a broad black area on back, enclosing an oval light gray-brown region at the tip of the pectoral, and extending forward dorsally to eye; a long light yellowish brown triangle (bright yellow in life) with apex anterior to caudal spine and base formed by truncate posterior margin of caudal fin; upper and lower lobes of caudal fin black, this color confluent with the black area of the back; pectoral fin dark gray on first two principal rays and basal two-thirds of remaining rays; dorsal and anal fins with basal half yellowish gray and distal half dark gray; pelvics yellowish gray.

Fowler and Bean (1929: 206, fig. 10) show variation of color markings of this species with age.

Smaller than any of the specimens figured by Fowler and Bean is one, 30 mm. in standard length, collected in shallow water at Biak, Schouten Islands, in April, 1945, by Frederick M. Bayer. His unpublished painting is reproduced as Figure 8. The specimen had a bright blue body, yellow tail, and black markings as shown.

Acanthurus triangulus Cuvier and Valenciennes was described from an old drawing by Vlaming. It appears to be *Paracanthurus hepatus* with the black and yellow colors reversed.

P. hepatus is known from East Africa to the Philippines and the Riu Kiu Islands. It does not appear to range throughout the tropical Pacific, the only record from this vast area being that of Günther (1873) from the Gilbert Islands.

Three different species of surgeon fishes of five prelinnaean authors were cited by Linnaeus (1766: 507) under the specific name *hepatus*. Cuvier and Valenciennes (1835: 183) were the first to realize this confusion and used the name for the East Indian species of Seba (1734: 104, pl. 33, fig. 3) which is easily recognized as *Paracanthurus* (see de Beaufort, 1951: 133, for further discussion). The Atlantic species of *Acanthurus* usually called *hepatus* must therefore be given another specific designation. *Acanthurus chirurgus* (Bloch) is the first available name.

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The Hawaiian Fishes of the Family Moringuidae: Another Eel Problem[1]

WILLIAM A. GOSLINE AND DONALD W. STRASBURG

INTRODUCTION

A SIMPLE attempt to identify the Hawaiian species of the family Moringuidae has brought us face to face with another "eel problem." In some ways our difficulties parallel those encountered many years ago with the freshwater eel (*Anguilla*), but in others they appear to be more complex. The biological problems in the Moringuidae have not passed unnoted (cf. Parr, 1930: 14), nor are we able to give final answers to them. However, the improbability that such answers will be forthcoming in the near future leads us to present our data and preliminary interpretations here. These should at least serve as warnings concerning the pitfalls that lie in the road to moringuid classification.

Our data consist of two rather separate segments. Those dealing with the Hawaiian material are primarily the responsibility of the senior author. The information on the large moringuid collections in the U. S. National Museum has been gathered by the junior author. These collections have been made available to us through the kindness of Dr. L. P. Schultz, to whom we are deeply obligated.

We should also like to thank the staff of the Pacific Oceanic Fishery Investigations for permission to use their X-ray apparatus, and Dr. George Henry of Honolulu for the donation of the X-ray film.

Up to the present time three different morphological types of moringuid eels have been taken in Hawaii. All three are known to us only from small patches of sandy bottom, to the surface of which they have been brought by the use of rotenone.

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[1] Contribution No. 71, Hawaii Marine Laboratory.

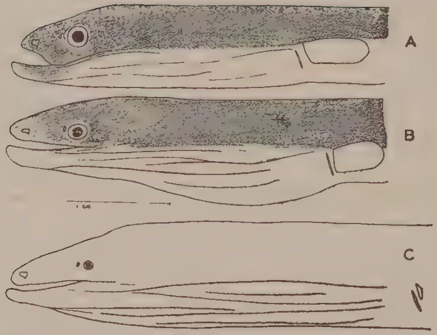

Fig. 1. Heads of three forms of Hawaiian *Moringua*. A—maturing male; B—maturing female; C—immature.

IMMATURE FORM

By far the commonest of the three different morphological forms is a yellowish, worm-like creature, with small embedded eyes and rudimentary fins (Figs. 1c and 2c). This type has been described as *Moringua hawaiiensis* by Snyder (1904: 517, pl. 3, fig. 6). More than a hundred specimens, ranging in length from 102 to 415 mm., have been taken by us in Hawaii at various seasons of the year (Table I). In its typical condition this form shows no indication of sexual maturity; though we have made repeated attempts to find gonads, we have either been totally unsuccessful or we have come to a rather dubious decision that the specimen was an immature female.[2]

One of the peculiarities found in the genus *Moringua* is that it may have the heart far behind the normal position below the pectoral fin bases. Apparently this is the only genus of eels, or of fishes for that matter, in which the heart shows a significant backward displacement. We have compared the gross structure of the heart of the above form (which has the heart well back as just described) with that of *Conger cinereus*. Aside from the weaker development of the pericardial membranes and the walls of the bulbus and ventricle of *Moringua*, no significant differences could be found. In both genera the heart seems to have essentially the same gross structure as that shown by Goodrich (1909: fig. 69F) for *Salmo*; there are no valves within the bulbus arteriosus itself.

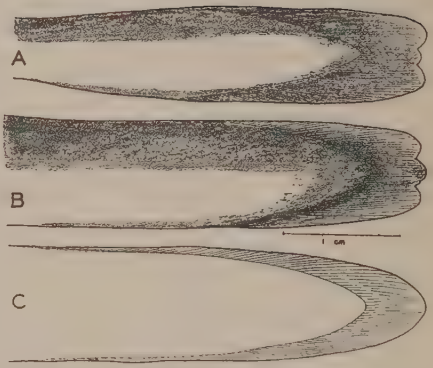

Fig. 2. Tails of three forms of Hawaiian *Moringua*. A—maturing male; B—maturing female; C—immature.

In the form of *Moringua* under consideration, the heart holds its usual position in relation to the liver (which lies directly behind the heart). Consequently the front of the liver also lies farther back than usual in the body. Directly behind the liver and gall bladder lies the elongate, I-shaped stomach with the pylorus far forward. The form and relative positions of the various digestive organs are similar to those found in other eels (cf. Suyehiro, 1942: 84–89), except that in *Moringua* most of the structures are more elongate.

MATURING FEMALES

The second of the three Hawaiian forms of Moringuidae is best represented by an apparently ripe female, 265 mm. long, taken off Waikiki on December 31, 1952. (This specimen was captured along with 20 immatures of the type previously discussed. These immatures ranged from 106 to 387 mm., and five of them were larger than the mature female; none of them could be sexed.) The ripe female (Figs. 1b and 2b) differs from the immature specimens in having the flesh over the eye clear rather than opaque, the eye itself larger (Table II), the pectoral fins well developed, a distinct but low dorsal and anal fin developed ahead of the caudal, and a trilobate tail. In coloration the specimen is dark above and silvery below. Internally, the heart is well back in the body, as in the immatures. Eggs fill much of the body cavity forward to the liver, and the stomach is present as a flabby, empty caecum.

Fortunately, a collection of *Moringua* taken some ten miles from Waikiki on September 26, 1953, includes various intermediate stages between the immature and mature forms discussed above. It is apparent from this collection that the various features differentiating the ripe female from the immature, i.e., changes in coloration and in eye, fin, and egg size, all occur more or less concomitantly (Table II). In this collection once again some of the largest specimens show no sign whatever of maturing

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[2] The fat bodies may be easily mistaken for female sex organs in these immature fishes, and certain identification of their gonads must await a more detailed histological examination than we have been able to make.

It seems to us that the specific identity of the two forms discussed above is certain. If this is correct, two features regarding them may be advantageously discussed here.

Taxonomically, the moringuid eels have often been divided into two sections, as by Weber and de Beaufort (1916: 337), depending upon whether the fins are rudimentary (*Aphthalmichthys*) or developed (*Moringua*). Whatever the situation may be with other species, the Hawaiian form apparently passes through both an *Aphthalmichthys* (immature) and a *Moringua* (mature) stage. Schultz (1953: 86, 88) did not divide the family into two sections, but did use the same characters of fin development to distinguish Marshallese species. Thus our immature Hawaiian form seems to be the same as Schultz's *Moringua abbreviata*, the mature female the same as *M. bicolor*, whereas Schultz's *M. macrocephala* represents an intermediate stage of maturity between the first two. (The Marshallese specimens identified as these three species have been reexamined by one of us).

Biologically, all of the changes that take place in the maturing female point to a change from a subterranean toward a pelagic existence. Further evidence for this supposition comes from the fact that mature (but so far as we know, no immature) moringuids have been taken at a night light in other regions (cf. Gordon, 1954: 12).

One other matter may be noted here. Our own data (Table I) indicate a seasonal spawning of the Hawaiian form of *Moringua*. If so, length frequency modes might well be expected among Hawaiian immatures. However, such modes are not obvious in the rather small samples of immatures available to us.

MATURING MALES

The third Hawaiian form is either the male of the forms just described, or it belongs to an entirely different genus and species. It is represented by eight specimens 155 to 183 mm. in length. The first of these was taken on February 9, 1952, along with three representatives of the immature form previously discussed. Six more were collected from a rotenone station on December 31, 1952, together with 20 immatures and one ripe female. An eighth was taken on December 11, 1953, with 10 immatures.

TABLE I

DATES OF CAPTURE (BY MONTH) OF THE THREE HAWAIIAN FORMS OF MORINGUIDAE

Form	Month											
	Jul.	Au.	Se.	Oc.	No.	De.	Ja.	Fe.	Ma.	Ap.	Ma.	Ju.
Immatures	..	..	X	..	X	X	..	X	X	..	X	X
Maturing females	..	..	X	..	..	X	..	..	..	..	..	..
Maturing males	..	..	..	..	..	X	..	X	..	..	..	.

There is a marked superficial resemblance between our mature males (Figs. 1a and 2a) and the mature females described above, in coloration, appearance of the eye, fin development, etc. Indeed Schultz (1953: 86, 88), while dividing up his species on the basis of sexual maturity, has included both males and females in at least two of them (*Moringua bicolor* and *M. macrochir*). Nevertheless the structural differences between our mature Hawaiian males and mature females are formidable. In the first place, the males are always much smaller than the females. In the adult males (but not the females) the upper lip projects down over the lower lip laterally. The maxillary teeth are lacking and the other dentition is reduced. Both the eye (Table II) and the head are relatively larger. There are about 6 fewer vertebrae and 7 fewer lateral-line pores on the average than in maturing females (Table IV). Finally, and probably most significantly, the heart in males is in its normal forward position. In almost all these features our males resemble the eel from the West Indies described as *Anguillichthys bahamensis* by Mowbray (in Breder, 1927: 10) and discussed at length by Parr (1930: 14), Trewavas (1932: 642), and most recently by Gordon (1954).[3]

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[3] Though the taxonomic status of the West Indian forms has been treated repeatedly, cf. Gordon (1954: 12), certain problems remain unanswered. As these are of some importance in connection with the present paper as well as for their own sake, they will be treated in some detail in the following paragraph.

The genus and species *Anguillichthys bahamensis* was described as new by Mowbray, who erected for it a new family,

TABLE II

CERTAIN FEATURES OF THREE HAWAIIAN FORMS OF MORINGUIDAE

Sex and maturity	Locality and date	Standard length (mm.)	Pigmentation symbol*	Eye diameter†		Pectoral fin (in thousandths of S. L.)		Caudal fin	Diameter of larger eggs (mm.)
				A	B	Length	Width of base		
Immature (♀?)	Waianae, Sept. 20, 1953	341	0	2.0	30	1.5	2.4	Rounded	(None found)
" "	"	343	0	1.7	26	1.5	2.4	"	" "
Maturing ♀	"	327	1	3.1	45	3.4	3.4	"	0.2
" "	"	336	1	3.3	44	5.1	3.6	"	0.2
" "	"	346	2	2.9	43	2.9	3.2	"	0.2
" "	"	368	2	3.3	50	6.0	4.4	Subtruncate	0.4
" "	Waikiki, Dec. 31, 1953	265	3	4.9	65	9.4	4.5	Trilobed	0.5
Maturing ♂	"	159	2	6.3	59	20.7	8.2	Bilobed	...
" "	"	155	3	10.3	84	25.8	12.2	"	...
" "	"	156	3	10.2	84	25.0	12.2	"	...
" "	"	174	3	10.3	86	25.2	8.6	"	...
" "	"	177	3	7.9	70	20.8	8.5	"	...

* 0 represents plain yellowish pigmentation; 3, blackish above and silver below; and 1 and 2, intermediate color phases.
† A = thousandths of standard length; B = thousandths of head length.

However, when the U. S. National Museum material (mostly from the Marshalls) of what appears to be the same species as found in Hawaii is investigated, it is discovered that many of the differences between males and females partially break down (compare Tables II and III). In addition to the characters given in these tables, it should be added that some Marshallese males have a few maxillary teeth as in females. Furthermore, the heart in Marshallese males, though sometimes as far forward as in Hawaiian males, is often located as far back as in Hawaiian females.

The two meristic differences between males and females, which seemingly occur in both Hawaiian and Central Pacific specimens, must be dealt with in somewhat greater detail. There would seem to be little doubt about the validity of the average difference between the pore counts of males and of females (Table IV). However, if the pore counts of males, females, and immatures of different sizes are plotted against standard length (Fig. 3), it can be seen that the pore counts of the immatures increase with increasing length up to about 200 mm. and that the pore counts of the males agree with those of immatures of the same size. Perhaps, the hypothesis might be erected that pore count is related directly to size (regardless of sex) and that the lower pore counts of males are simply due to the fact that males are smaller than

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Anguillichthyidae. There seems to be nothing in Mowbray's description to distinguish this family from the Moringuidae. Parr (1930: 14) recorded further specimens of Mowbray's species, some of which were taken at a night light together with a ripe female eel (similar to our ripe female form). Parr identified the Bahamas female as *Stilbiscus edwardsi* Jordan and Bollman (1889: 549), the holotype of which is a maturing female with well-developed eggs. Parr sexed several of his *Anguillichthys*-type eels and found them all to be running-ripe males. On the basis of the similarities between *Anguillichthys bahamensis* and *Stilbiscus edwardsi*, and because both have been taken at the same night-light station, Parr synonymized *Anguillichthys* with *Stilbiscus*, strongly suggesting that the two forms may actually represent males and females of the same species (though he provisionally maintained them as distinct but congeneric). After dissecting "*Anguillichthys*" but not "*Stilbiscus*," Parr proposed the family name Stilbiscidae for the two forms. His definition of the family is as follows: "Closely related to the Moringuidae from which the present family mainly differs in having the parasphenoids well separated from the frontals, and in the peculiar differentiation of the vertical fins." As Trewavas (1932: 646) has noted, the nature of the vertical fins does not distinguish the Stilbiscidae from the Moringuidae. The osteological character given by Parr needs fuller consideration. In at least some other eels this particular character has no value; for example, various specimens of a single species of *Anguilla* may show either the moringuid or the stilbiscid form of the frontal-parasphenoid feature given by Parr (cf. Regan, 1912: 378). Nevertheless, this does not prove the character valueless in the eel group under discussion. Indeed, Trewavas' work indicates that it may well serve to distinguish Mowbray's *Anguillichthys* from *Moringua*. But what is the status of this character in *Stilbiscus edwardsi*? Does *Stilbiscus* have the character on which Parr erected the family Stilbiscidae? Is the character simply related to the sex of the individual? Trewavas (*loc. cit.*) has solved the difficulties arising from these questions at the family level by synonymizing both the Stilbiscidae and the Anguillichthyidae with the Moringuidae. The question remains of whether the genera *Anguillichthys* and *Stilbiscus* are separate and valid, whether one should be synonymized with the other, or whether one or both should be synonymized with *Moringua*.

TABLE III

CERTAIN FEATURES OF THREE CENTRAL PACIFIC FORMS OF MORINGUIDAE

Sex and maturity	Locality and date	Standard length (mm.)	Pigmentation symbol*	Eye diameter†		Pectoral fin (in thousandths of S. L.)		Caudal fin	Diameter of larger eggs (mm.)
				A	B	Length	Width of base		
Immature (♀?)	Bikini, 8/47	189	0	1.1	16	1.6	1.6	Pointed	(None found)
“ “	“ “	222	0	1.2	16	1.4	1.6	Rounded	“ “
“ “	“ “	237	0	1.1	17	1.3	1.3	Pointed	“ “
“ “	“ “	275	0	1.1	16	1.1	1.8	Rounded	“ “
“ “	“ “	300	0	1.3	22	1.7	2.7	“	“ “
Maturing ♀	“ 8/46	213	1	3.3	45	7.5	4.7	Subtruncate	0.15
“ “	Samoa, 6/39	240	2	3.8	51	7.9	4.2	Truncate	0.15
“ “	Bikini, 8/46	258	1	2.7	37	5.8	3.5	Subtruncate	0.15
“ “	“ 8/47	260	1	3.8	50	11.2	3.8	Trilobed	0.3
“ “	“ 8/46	263	1	3.0	42	6.8	4.2	Subtruncate	0.15
“ “	“ 8/47	280	1	4.3	56	11.4	3.9	Trilobed	0.2
“ “	Samoa, 6/39	282	2	5.0	65	12.4	3.9	Bilobed	0.5
“ “	“ “	290	3	4.8	64	11.0	3.4	Trilobed	0.5
“ “	Bikini, 8/47	314	1	3.8	56	10.5	3.5	“	0.25
Maturing ♂	“ 8/46	125	1	8.0	69	24.0	9.6	“	...
“ “	“ “	131	1	7.6	68	22.1	6.9	“	...
“ “	“ 8/47	132	1	7.6	74	21.2	6.1	Bilobed	...
“ “	“ 8/46	137	2	8.8	74	21.9	8.8	“	...
“ “	“ 8/47	140	1	7.1	69	18.6	5.0	Trilobed	...
“ “	Guam, 1/46	159	2	9.4	84	22.0	9.4	Bilobed	...

* As contrasted with Table II, these specimens are arranged in order of their increasing standard length within sex categories. Pigmentation symbols are based on specimens which were in alcohol for 7–15 years and undoubtedly somewhat faded. 0 represents plain yellowish pigmentation; 3, blackish above and silvery below; and 1 and 2, intermediate color phases.

† A = thousandths of standard length; B = thousandths of head length.

females. The following facts fall into line with such a hypothesis. It is known that the lateral line in fishes develops from front to rear. Therefore, if the lower pore counts of smaller specimens is due to incomplete development of the lateral-line system, the distance from the last lateral-line pore to the base of the tail should be a greater proportion of the standard length in small (less than 200 mm.) than in large specimens (over 200 mm.). This proves to be true. Our smallest Hawaiian specimen (102 mm.) has an unusually low pore count of 92, and an exceptionally high distance from the last pore to the tail, of 150 thousandths of the standard length. In males (Table IV) averaging 170 mm., the mean pore count is 98 and the distance from the last pore is 79 thousandths. In specimens over 200 mm. (Table IV) the mean pore count is about 106 and the lateral line to caudal distance about 55 thousandths of the standard length (48 thousandths in our females, 59 in our immatures). Despite the general agreement between the above evidence and the hypothesis mentioned, it would seem inadvisable to pin too much faith in it because of the following, indirectly contradictory evidence.

It seemed to us that if, despite the difference in male and female pore counts, the number of vertebrae in the two sexes were the same, then the hypothesis that pore count increased with length up to 200 mm. would be on firm ground. However, male and female vertebral counts definitely differ[4], as shown by Table IV. That there should be an increase in vertebrae with increasing standard length seems doubtful,

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[4] These counts are all based on X-rayed material. The X-ray technique did not prove entirely satisfactory here, and in about half the specimens the vertebrae could not be counted with certainty. Such specimens, which include all of the small immatures, have been omitted from the present data. The small specimens appear to have poorly ossified vertebrae, and all specimens tended to have kinks in more than one plane, some of which would lift parts of the specimen off the film and out of focus.

TABLE IV

VERTEBRAL AND LATERAL-LINE PORE COUNTS OF HAWAIIAN MORINGUIDAE

Sex	Standard length (mm.)	Number of vertebrae	Pores from gill opening to end of lateral line	Vertebrae minus pores	Distance from last pore to base of tail in thousandths of S. L.
Maturing male	156	120	95	25	102
" "	167	118	97	21	72
" "	174	120	95	25	91
" "	177	122	104	18	50
Average	168	120	98	22	79
Maturing female	265	130	101	29	68
" "	327	122	108	14	36
" "	346	127	106	21	44
" "	368	127	106	21	45
Average	320	126	105	21	48
Immature	219	127	105	22	50
"	220	126	108	18	50
"	235	128	107	21	64
"	245	127	106	21	61
"	247	127	106	21	61
"	261	128	107	21	69
"	321	128	106	22	65
"	408	127	105	22	54
Average	270	127	106	21	59

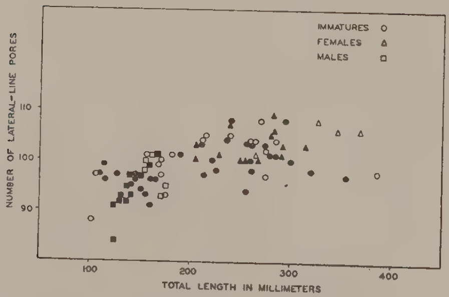

Fig. 3. Relationship between pore count and length in *Moringua*. Hollow symbols represent Hawaiian specimens; solid symbols represent U. S. National Museum specimens, mostly from the Marshall Islands, with a few specimens from Samoa and Guam.

though our present data are insufficient to prove that such an increase does not occur.

One of the purposes of making vertebral counts was to determine the extent of the correlation between vertebral and pore counts. There is, it appears, one pore per vertebra. The greater number of vertebrae than pores arises from the fact that there are several pores and vertebrae ahead of the point (over the gill openings) at which we started our lateral-line counts and several more vertebrae behind the last lateral-line pore. Apparently the excess of vertebrae over pores is about the same in our males, females, and (large) immatures (Table IV). There is, however, a considerable individual variation in this excess; and as the pore count in eels seems to be a good indication of vertebral number (Gosline, 1951: 303), it is of some importance to know where this variation arises.

Our belief is that the individual variation in the difference between vertebral count and pore count stems primarily from the fact that in some individuals the lateral line extends somewhat farther back than in others. If this is correct, then the differences between vertebral and pore counts should be correlated with the distance (relative to standard length) between the last pore and the base of the caudal. The correlation coefficient for these features, in the specimens over 200 mm. in Table IV, is .60, indicating that such a correlation does exist. The low value of this figure, however, also indicates other sources of variability besides the backward extension of the lateral line as the cause of the discrepancy between pore and vertebral count.

One might anticipate in moringuids, as in *Anguilla*, a certain amount of divergence at sexual maturity from an immature form in which the sexes were approximately similar. However, it seems most unlikely that our male moringuids ever passed through a stage similar to that of our immature females. For one thing, the head length of our males is relatively greater than it ever becomes in our females and immatures, and there is no indication that in females the head length increases at the onset of sexual maturity. (Though our data on this point have not been given here, the same thing is shown by Gordon, 1954, Table I, for the West Indian species). Second, the eye is larger than it ever becomes in our females. Third, that the generally more forward position of the male heart makes a change from the immature form into the adult male seems most improbable. It seems unlikely that in males the heart should undergo a backward displacement, such as is found in immatures, only to return toward its normal position with maturity, particularly as there is no such return movement in females.

We have examined all of our immature Hawaiian moringuids, especially the smaller specimens, to see whether any of them showed either the heart in the forward, male position or intermediate in location between the conditions found in males and females (and thus indicating some change in position with growth in males). No evidence for either of these possibilities was found. Consequently, the conclusions seem warranted that our immatures are all females, and that immature males have yet to be taken despite special efforts on our part to collect them.

Several factors point to the hypothesis that the immature form of our adult males more or less drastically curtails or totally omits the period of subterranean existence found in immature females. For one thing, although we have taken small but approximately equal numbers of maturing males and females and numerous immature females, we have apparently never, as stated, collected immature males. Second, the fact that immature, fossorial females from 102 to 415 mm. in length have been collected, but that our largest ripe male is only 183 mm. long, indicates at least that the amount of growth in the subterranean phase of the male cannot be as great as that of the female. Last, certain features common to the fossorial stages of other moringuids are absent from our maturing and presumably from immature males, e.g., posterior heart position; this at least suggests a different mode of life for the immature male.

As to the question of whether or not our males belong to the same species as our females and immatures, no final proof can be given at this time. If they represent the same species, then this species shows a sexual differentiation that is almost unbelievable for fishes. If they represent a different species and genus, then some very peculiar circumstances remain to be explained. In the first place, where are the females of the species for which we have males and where are the males to correspond to our females? Why should the males of one species and the females and immatures of another be taken in the same habitat? (These same two questions have already been asked by Parr in relation to the two Atlantic forms discussed in footnote 3). We have never taken males in Hawaii without also taking immature females, and we have collected mature males and females and immatures from the same small section of a rotenone station. Again, (Table I) the ripening of the two sexes seems to occur at the same general season. Finally, the males, females, and immatures agree well in certain features such as the position of the anus, etc., and the ripening males and females agree in coloration. Because of all these considerations we provisionally prefer the hypothesis that our male, female, and immature moringuids all represent a single species. It would take only a single Hawaiian specimen, e.g., a female "*Anguillichthys*" or a male *M. abbreviata* type, to disprove this hypothesis, but so far we have looked for such a specimen in vain.

The name to be applied to our species remains to be discussed. As already noted, the names *M. abbreviata*, *M. macrocephala*, and *M. bicolor* as defined by Schultz all seem to be applicable to female and immature forms of our species. However, the oldest name available for it seems to be *Moringua macrochir* Bleeker, which Schultz (1953: 93) used primarily (but not entirely) for males of what we believe to be the same species. It is therefore *M.*

macrochir that we provisionally apply to all the forms we have been discussing.

Comparison with Other Eels

Though there appears to be only one moringuid in Hawaii, *M. macrochir*, there are certainly others elsewhere in the Central Pacific, e.g., in the Marshalls. We have not studied these in detail but it may be helpful to state our basis for differentiating them from *M. macrochir*. On the basis of the U. S. National Museum material, we have concluded that all the Central Pacific moringuids with the lower jaw protruding and with pore counts from 84 to 110 belong to *M. macrochir*.

Morphologically, the most aberrant form of the Hawaiian moringuid is the immature, worm-like, burrowing (female?). There are in Hawaii several eels belonging to other families that have taken up a similar habitat. Some of the salient biological features of two of these are compared with *M. macrochir* in Table V. In none of these is there any great sexual differentiation or external change with the onset of sexual maturity.

Finally the resemblances between the life histories of moringuids and anguillids should be noted. These two eel families seem to be about the only ones having members (apparently only one species in the Moringuidae) that habitually spend part of their lives in fresh water. These families are also the only ones to our knowledge in which certain species at least undergo very striking (and more or less parallel) changes in external morphology at the onset of sexual maturity. Both of these features suggest a genetic relationship between the two families despite their rather different appearance. This suggestion is borne out by the osteology of the two families (Regan, 1912). If from this relationship one can gain some criterion concerning primitiveness in the family Moringuidae, then it is again the "*Anguillichthys*" form of moringuid represented by the males of our species that is the least specialized.

Summary and Discussion

An attempt to identify the Hawaiian species of the eel family Moringuidae has led us into rather numerous and difficult problems. Some of these have been more or less satisfactorily solved; others remain wide open. To facilitate future work we present in this summary first those facets of the investigation for which a particular solution is rather strongly indicated, followed by those aspects for which interpretations become increasingly undocumented.

A more or less complete transition has been demonstrated between the small-eyed, yellowish, rudimentary-finned immature Hawaiian form and the larger-eyed, silvery, longer-finned adult female. The former has been identified among Marshallese specimens by Schultz (1953: 86) as *Moringua abbreviata*, the latter as *M. bicolor; M. macrocephala* of Schultz is a form ontogenetically intermediate between these two.

The morphological changes that occur with the onset of female sexual maturity seem to be associated with a change from a fossorial to a pelagic mode of life. Similar developmental differences are known to occur in *Anguilla*, but do not take place in Hawaiian fossorial eels other than *Moringua*.

Table V

Maturation in Hawaiian Burrowing Eels

Family and species	Differences between maturing males, maturing females, and immatures	Ripening males		Ripening females	
		Number	Size range (mm.)	Number	Size range (mm.)
Moringuidae *Moringua macrochir*	Great	8	155–183	5	265–368
Ophichthidae *Caecula platyrhyncha*	None	3	280–305	12	285–355
Muraenidae *Uropterygius marmoratus**	None	4	220–330	7	235–305

* This species inhabits rocky areas and is less strictly a fossorial form than the other two.

Passing to those features of the investigation for which our evidence is less secure, we believe that our mature Hawaiian males represent the same species as our females and immatures. Marshallese males corresponding to the Hawaiian males have been identified by Schultz as *Moringua macrochir*. Morphological differences similar to those between Hawaiian males and females occur in the West Indian moringuids. These differences include such features as heart position and vertebral count, as well as a number of less important characters.

Third, there remain the problems for which we have at present no answers. First, where are the immature males? Despite serious effort, we have been unable to show any transition between any immatures and the mature male form. Because our immatures resemble the maturing females far more than the males, we have provisionally identified all of our immatures as undeveloped females. Also, why does such a great morphological difference exist between the sexes in our moringuids when the males and females of other Hawaiian eels are strikingly similar? In an attempt to provide an answer to the above two questions, we have suggested the working hypothesis that the males may rather drastically curtail or omit the immature fossorial and morphologically specialized stage found in females.

Another unsolved problem arises from the sizes of immature females. From all of the stations at which we have taken maturing females, we have also taken specimens, showing no signs of maturity, that are larger than our largest mature forms. There would seem to be at least three possible answers to this problem, i.e., that the large immatures are sexually abnormal, that they are out of phase with the spawning cycle of the smaller maturing females, or that they represent a different species. Regarding the third possibility, we can find no morphological differences between the large immatures and smaller ones. Regarding the second, we have at least the evidence that female maturity in Hawaii occurs at various sizes from 265 to 365 mm. This would throw no light on the problem of our very large immatures if our moringuids spawned more than once. But it seems more likely that our Hawaiian moringuids, like *Anguilla*, spawn once and die. Perhaps the same reason why some of our females mature at 265 mm. and others at 343 mm. will explain why still others remain immature at 415 mm. In any event, there is no strict correlation between either size and female maturity or size and female immaturity.

Finally, we find in the Hawaiian *vs.* Marshallese moringuids a problem held in common with many other fishes (Gosline, 1955: in press). In Hawaii, moringuid spawning appears to occur only in winter; in the Marshalls it takes place in the same species in the summer and presumably all year around. If moringuids are basically tropical fishes, as everyone assumes they are, then one would expect them on moving into the colder Hawaiian waters to restrict the spawning period to the warmest, not the coldest months (Ekman, 1953: 113). The reversal of the expected spawning period in Hawaiian waters remains unexplained for *Moringua* as for many other fishes.

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Submarine Topography South of Hawaii[1]

K. O. EMERY[2]

Reprinted from PACIFIC SCIENCE
July, 1955

Submarine Topography South of Hawaii[1]

K. O. EMERY[2]

GEOMORPHIC AND STRUCTURAL evidence strongly suggests that the center of volcanism in the Hawaiian Islands has migrated slowly from northwest to southeast. This movement is reflected in a progression from the eroded and reef-covered volcanic platform of Midway Island to the periodically active volcanoes of Kilauea and Mauna Loa on the island of Hawaii. From the general age relationships of the islands it might be supposed that a still younger center of volcanism may now be building one or more new cones on the sea floor southeast of Hawaii, eventually to form new islands at that end of the chain.

Soundings shown on charts of the area south and southeast of Hawaii prior to 1954 were taken mostly by various ships that happened to be passing through the area. They are too sparse and poorly positioned to reveal many details of the topography; however, several single isolated soundings on U. S. Coast and Geodetic Survey Chart No. 4179 suggested the presence of as many separate submarine mountains. At the request of the Office of Naval Research the Commander Service Forces Pacific made available a ship for a brief bathymetric survey of these areas. This ship was U.S.S. Patapsco, AOG 1, a 16,000 barrel 10-knot oil tanker that carried a NMC-2 echo-sounder. The great stability of the ship permitted routine sounding operations to be carried on in spite of the fact that most of the sounding traverses paralleled the trough of waves produced by winds of up to Force 6.

Appreciation is due Lt. J. W. Downing, commanding officer, and Lt. j.g. C. J. Kelly, navigator, for their cooperation and interest in the work. The Hawaiian names for the five seamounts were kindly supplied by Mrs. Mary K. Pukui and Mrs. Martha Hohu of the Bernice P. Bishop Museum in Honolulu and by Dr. Gordon A. Macdonald, director of Hawaiian volcano observatory. Dr. Macdonald kindly read the manuscript, suggesting several improvements. The study was made possible by funds provided by Office of Naval Research contract Nonr 228 (06).

METHOD

Between 0100 June 29 and 1000 July 2, 1954 about 800 miles of sounding traverses were run in the area of Figure 1. Soundings were read visually at one-minute intervals by crew-members but only alternate soundings were plotted on the base chart for Figure 1. Index error and motor speed error were constant within the accuracy of their measurement. Accurate positions were obtained within 4 miles of shore by visual pelorus bearings. Radar fixes to 15 miles from shore proved less reliable. Only star fixes could be used farther off-shore because the area is one of base line extension for Loran. Accordingly, the survey was set up in such a way that sounding in the nearshore areas was done during the daytime, and the long radial traverses were started from a land fix at dusk and ended with a landfall after dawn. Errors in the dead-reckoning positions at the ends of traverses were pro-rated over the entire traverses, taking into account ship speed and offsetting of the course by the wind and sea.

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About 2,430 two-minute interval soundings resulted from the survey. These soundings were plotted on U. S. Coast and Geodetic Survey Chart No. 4115 (1951 edition) which also contains 380 soundings in the area of interest. An additional 220 useful soundings were transferred to the plotting chart from a compilation made by Dietz and Menard (1953) for their general map of the Hawaiian region. A few additional old soundings were omitted because they differed markedly from others in the vicinity and were considered erroneous in position. The total of 3,030 soundings served as the basis for the sea floor contour lines of Figure 1.

Corrections for true sound velocity in the water were made using data from the Marshall Islands (Emery, Tracey, and Ladd, 1954) so that the contour lines would indicate actual depths. Contour lines of land topography at the same interval of 1,500 feet (250 fathoms) were added to the chart from the geological map of Hawaii (Stearns and Macdonald, 1946).

RESULTS

The survey shows the presence of three main physiographic units: lower slopes of Hawaii, Hawaiian Deep, and Hawaiian Arch (Figures 1 and 2). Superimposed on these units are five seamounts.

Lower Slope of Hawaii

The lower slope of the island of Hawaii extends a distance of between 10 and 20 miles from shore to a depth of more than 15,000 feet. Instead of being a simple smooth surface the slope has been made somewhat irregular by four kinds of secondary features. One such feature is volcanic cones, two of which are located directly south of Kilauea. These cones will be discussed in the section on seamounts. A second irregularity is that of elongate ridges that extend seaward off both South Cape and Cape Kumukahi. Both ridges are probably the result of vulcanism along rifts or zones of weakness, extensions of which have been recognized on land (Stearns and Macdonald, 1946, p. 25) and are exemplified by a row of many small craters between Cape Kumukahi and Kilauea Crater. As would be expected of volcanic activity, at least one hill rises above the general level of the outer end of the ridge off Cape Kumukahi. A second hill is shown on U. S. Coast and Geodetic Survey Chart No. 4115 to rise from depths of more than 1,800 feet to within 210 feet of the sea surface (35 fathoms—Existence Doubtful) at a point 5 miles off Cape Kumukahi, but detailed sounding traverses made in this area failed to reveal depths shallower than 1,800 feet. The ridges bear a striking resemblance to similar features of guyots in the Marshall Islands, particularly Sylvania Guyot near Bikini Atoll (Emery, Tracy, and Ladd, 1954).

The third kind of irregularity of the slope is a greater than usual steepness near the shore from south of Kilauea Crater northeastward to near Cape Kumukahi; this steepness is believed to result from the presence of a normal fault that is parallel to shore and is *en echelon* with faults of the Hilina zone on land. The latter is marked by two scarps 1,000 to 1,500 feet high and the scarp on the sea floor is nearly as high. The fourth and last kind of irregularity on the slope is a long broad low ridge that extends eastward from the northernmost parasitic cone. This area is one in which 4,553 earthquakes were detected in a six-week period of 1952 (Macdonald, 1952). Whether this low ridge is of volcanic or structural origin is unknown. The submarine slope appears to be free of a fifth kind of secondary land form, submerged wave-formed terraces, unlike the northeastern coast where Dietz and Menard (1953) reported an extensive terrace at a depth of 1,080 feet.

The steepness of the lower slopes was measured along 11 of the sounding traverses, using for each measurement the gradient of the steepest 6,000-foot depth zone and avoiding as much as possible the influence of secondary features. The mean of these values is 11°. In comparison, the maximum, mean, and minimum slopes of 6,000-foot height zones of the subaerial part of Mauna Loa were found to be 11°, 7°, and 3°, respectively. It is evident from these measurements as well as from inspection of the contour lines of Figure 1 and of the profiles of Figure 3 that the submarine slopes of this part of Hawaii are steeper than the subaerial slopes.

Hawaiian Deep and Arch

Beyond the foot of the lower slope of Hawaii is a broad depression that extends along most of the northeastern side of the entire chain and along part of the southwestern side, as mentioned by Stocks (1950) and described more fully by Dietz and Menard (1953). The 18,000-foot contour of Figure 1 shows the deepest part of the Hawaiian Deep; farther southwest the axis of the Deep shallows to 17,200 feet and its course is uncertain west of 155° 10′ W. owing to its low relief and the low density of soundings.

South and east of the axis of the Deep the bottom gradually becomes shallower until at the end of each long radial sounding traverse the depths are about 1,000 feet shallower than where the traverse crosses the Hawaiian Deep. This gentle northwestward-facing slope marks the inner side of the Hawaiian Arch, a 200-mile wide bulge that borders the Hawaiian Deep. The scarp that Dietz, Menard, and Hamilton (1954) found to border the outer edge of the Hawaiian Arch was not reached in this survey. In only a few places do the sounding traverses in the Hawaiian Deep and Arch have local depth variations that exceed 100 feet, the probable limit of accuracy of reading the echo-sounder; accordingly, it is supposed that the bottom is mantled by a thick layer of sediment.

The Hawaiian Deep is attributed by Dietz and Menard (1953) to crustal depression caused by the great load of the volcanic pile that comprises the Hawaiian Islands. The adjacent Hawaiian Arch they believed to be a related elastic bulge.

Seamounts

Five separate topographic highs were investigated during the survey. For convenience all will be called seamounts though three of them approach the lower limit of size and isolation required for application of the term, seamount, by the International Committee on Nomenclature of Ocean Bottom Features (1953).

Four of the seamounts were indicated by single soundings on previous charts (Table 1); however, the survey located new shallowest soundings as much as 4,100 feet shallower than the original ones (Table 1). One small deep seamount (*Hohonu*—"deep as a pit or

TABLE 1
CHARACTERISTICS OF THE FIVE SEAMOUNTS

	Present Survey—Corrected Feet	Previous Chart—Uncorrected Fathoms	Previous Chart—Corrected Feet	Height above Surroundings—Feet	Diameter of Base—Statute Miles	Mean Steepness of Slopes—Degrees
Papa'u	2490	450	2910	3000	6	9?
Loihi	3222	783	4932	9000	14	17
Wini	5346	990	6198	12000	20	16
'Apu'upu'u	5832	1600	9924	10500	21	18
Hohonu	11478	....	....	5500	6	20

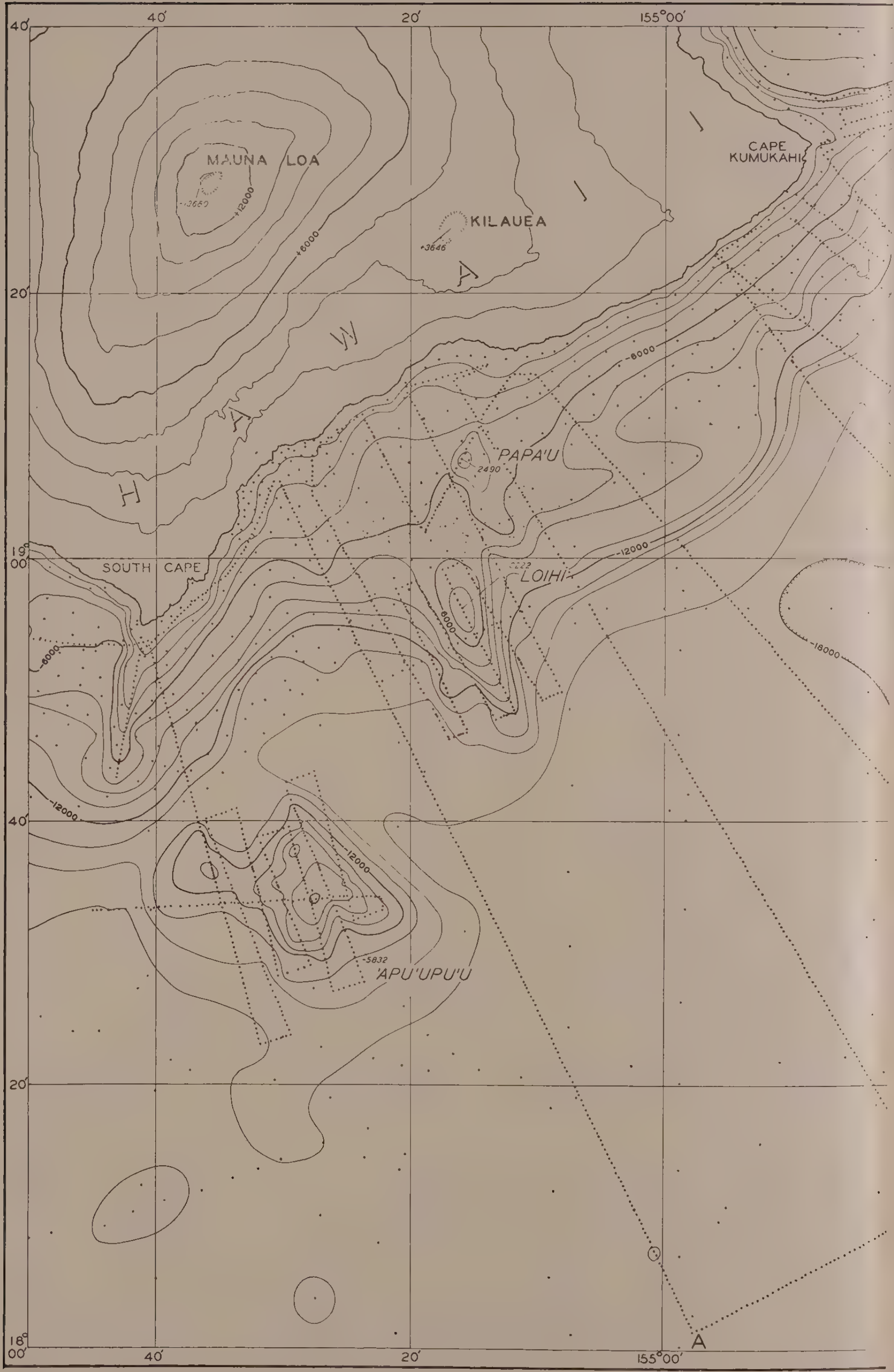
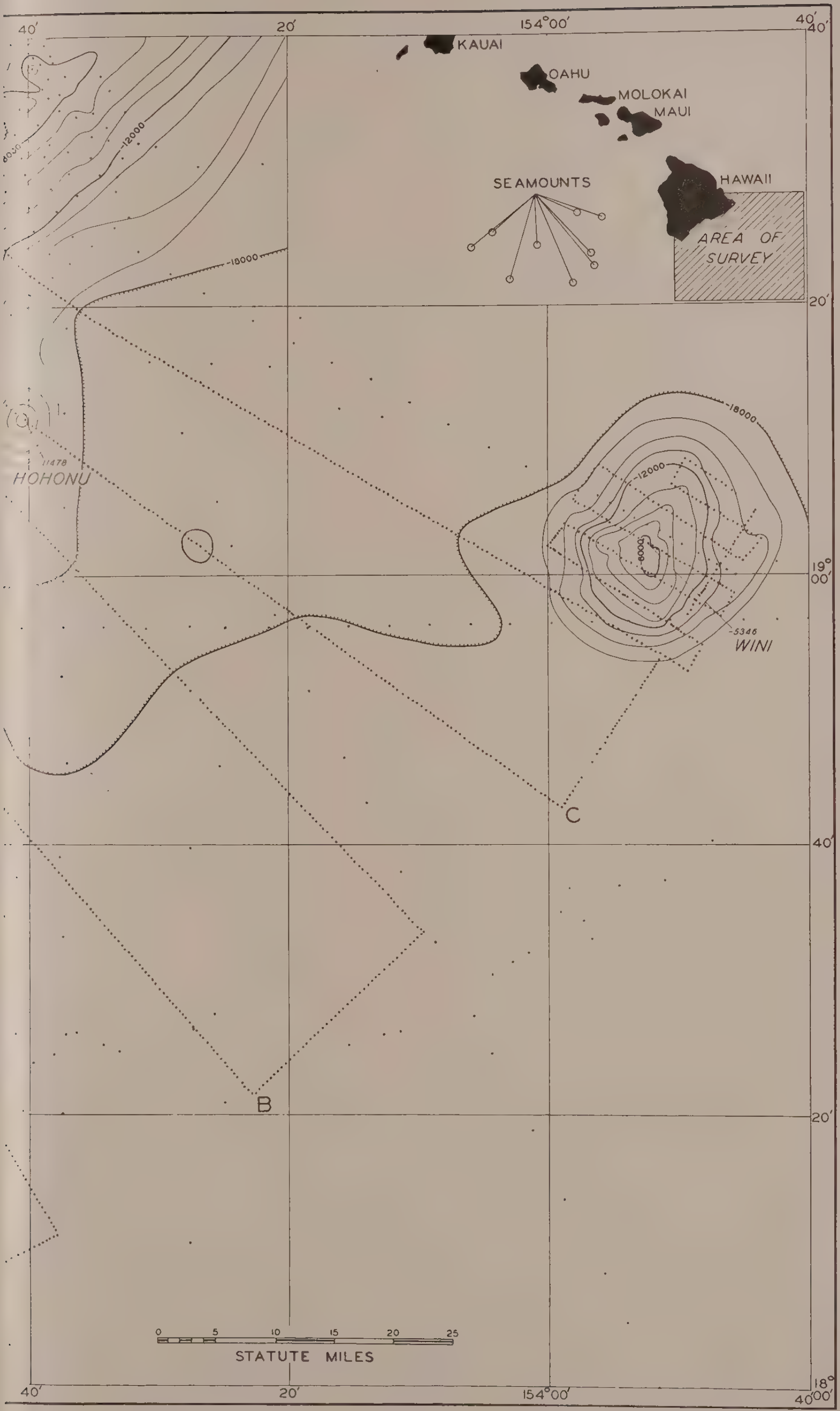

40'
20'
155°00'
40'
20'
19° 00'
40'
20'
18° 00'
MAUNA LOA
+12000
-13680
KILAUEA
+3646
+6000
H
A
W
A
I
I
CAPE KUMUKAHI
SOUTH CAPE
PAPA'U
2490
-3222
LOIHI
6000
-6000
-12000
-18000
'APU'UPU'U
-5832
A

FIG. 1. Map showing topography of southern portion of Hawaii and vicinity. Submarine topography based prin
feet (250 fathoms); large dots indicate soundings (those closely spaced were taken by the "Patapsco," the w


40′
20′
154°00′
40′
40′
KAUAI
OAHU
MOLOKAI
MAUI
HAWAII
SEAMOUNTS
AREA OF SURVEY
-12000
-18000
6000
20′
11478
HOHONU
-18000
-12000
-5346
WINI
19° 00′
C
40′
B
20′
0
5
10
15
20
25
STATUTE MILES
18° 00′
40′
20′
154°00′
40′

cipally on the survey of June 29 to July 2, 1954, made by the U.S.S. "Patapsco." Contour interval—1,500
idely scattered ones from other sources); finely dotted portion is the area of seismic activity in 1952.

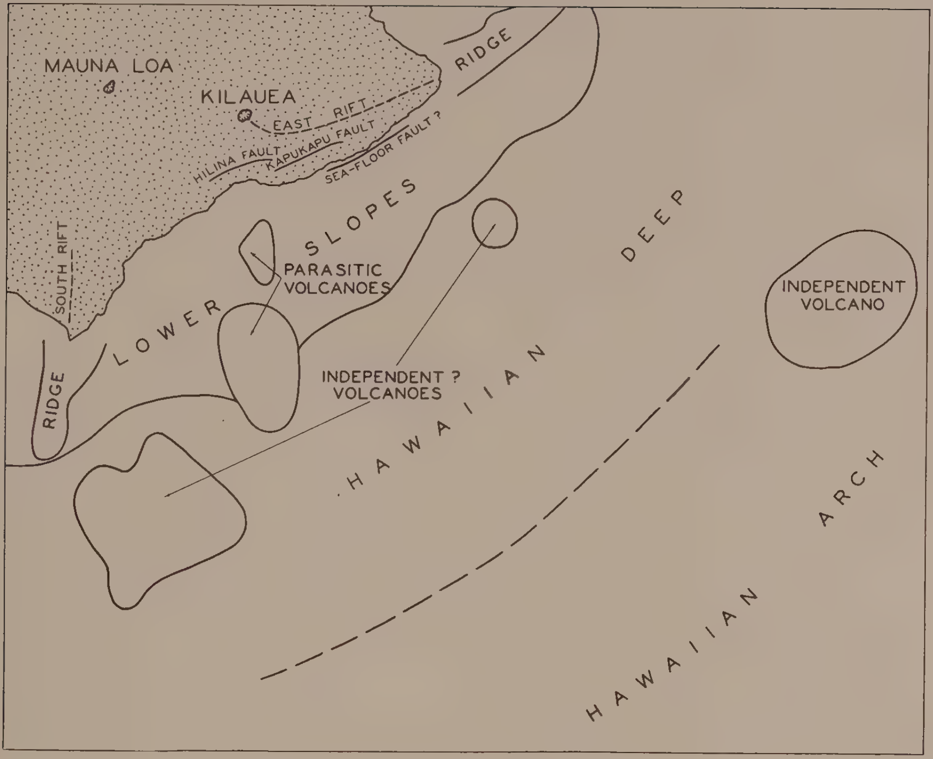

MAUNA LOA
KILAUEA
EAST RIFT
KAPUKAPU FAULT
HILINA FAULT
SEA-FLOOR FAULT ?
RIDGE
SOUTH RIFT
LOWER SLOPES
PARASITIC VOLCANOES
INDEPENDENT ? VOLCANOES
INDEPENDENT VOLCANO
RIDGE
HAWAIIAN DEEP
HAWAIIAN ARCH

FIG. 2. Physiographic interpretation of Figure 1.

well, the deep sea") was not previously known.

The mean basal diameters of the seamounts range from 6 to 21 miles, so that two of them are intermediate in diameter between the subaerial part of Lanai Island (13 miles) and Kauai Island (27 miles). The seamounts rise 3,000 to 12,000 feet above their surroundings, a relief that is about three times that of the subaerial portions of the various islands in the Hawaiian Chain when expressed as ratio of relief to diameter. The greater relief is, of course, also indicated by steeper slope: a mean of 17° for the seamounts as compared to 11° for the submarine slope of Hawaii and 7° for the subaerial slope of Mauna Loa (Table 1 and Fig. 3). If slope corrections had been applied to the soundings, the submarine slopes would have been slightly steeper.

One of the seamounts (*Wini*—"coming to a point, sharp pointed") is conical in shape, one (*Loihi*—"to extend, to be long") is elongate, one (*'Apu'upu'u*—"a rough, uneven surface, such as a hillock") is irregular with several peaks, and the other two smaller ones (Hohonu and *Papa'u*—"to be shallow, as water") are of uncertain shape, possibly conical. Small irregularities suggestive of craters are present at the tops of three (Wini, 'Apu-'upu'u, and Hohonu), though it is obvious that the existence of small craters cannot be proven without much more detailed surveys than this one. None of the seamounts has a flat top like guyots but then most of the seamounts are deeper than most guyots and they probably also are younger.

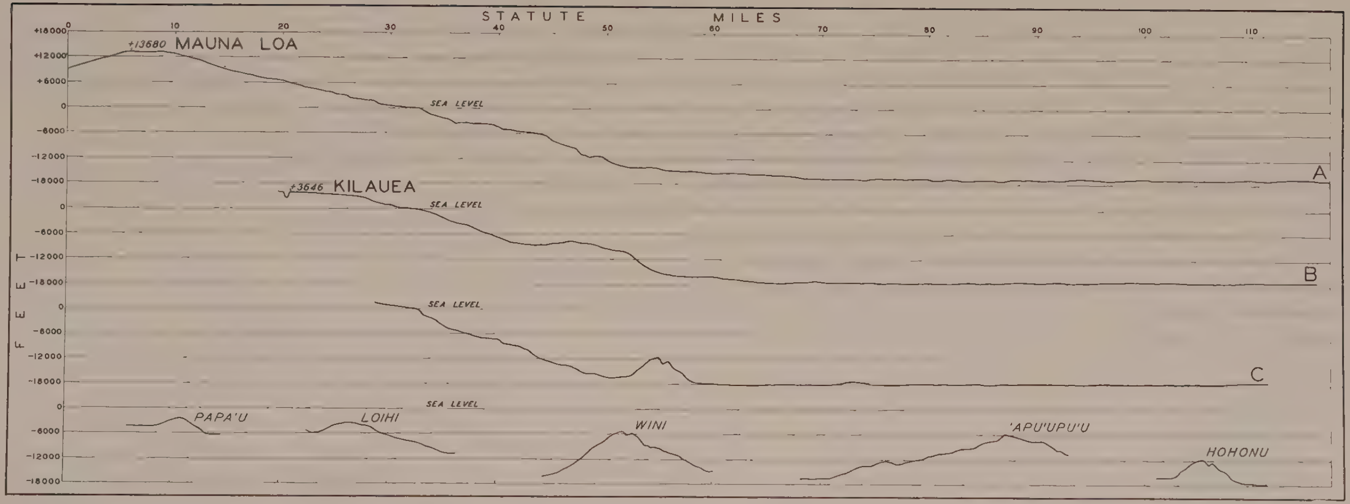


FIG. 3. Profiles of three sounding traverses (A, B, and C) of Figure 1 and of the five seamounts. Vertical exaggeration = 2.0. The slope from the top of Mauna Loa to the bottom of the Hawaiian Deep is the highest continuous slope in the world, approximately 32,000 feet.

None of the seamounts is seismically active within the limitations of the seismograph net on Hawaii. The 1952 belt of active seismicity south of Hawaii appears to pass between the two shallowest seamounts (Papa'u and Loihi) (Fig. 1), but conceivably some of the recorded seismic activity may still be related to them.

In summary the seamounts differ from the known Hawaiian volcanoes in some respects: higher relief (relative to diameter), steeper slopes, and lack of seismic activity. In spite of these differences the general shapes of the features and the geological and geographical environment is such that there is a high degree of probability that the seamounts are of volcanic origin, and correspondingly that the differences which exist may be indications of the nature of the early stages of a volcano forming well below sea level. If this conclusion is correct then the two shallowest seamounts (Papa'u and Loihi) must be considered parasitic (in the sense of topography—not activity) volcanoes on the flank of Kilauea-Mauna Loa, two ('Apu'upu'u and Hohonu) are probably independent volcanoes located at the foot of the slope, and one (Wini) is certainly an independent volcano, being located on the opposite side of the Hawaiian Arch from Hawaii (Fig. 2). If they are volcanoes, their age may be Late Tertiary to Pleistocene in accordance with the youth of the rest of the Hawaiian Chain. Quite probably they are even younger than the rest of the islands as suggested by the general movement of the center of volcanic activity from northwest to southeast (Stearns, 1946). It is impossible to state definitely, however, that the seamounts do constitute such an extension, but such is more likely than that they are unrelated and isolated volcanoes like the ones scattered about the area west of Hawaii (insert map of Fig. 1).

CONCLUSIONS

The relationship of Mauna Loa and Kilauea to the lower slope of Hawaii and its parasitic cones, ridges, fault scarp, and belt of seismic activity, to the Hawaiian Deep and Arch and to superimposed seamounts is such that it is exceedingly desirable to obtain more information on the submarine topography and bottom materials of the region. This is even more important in a geophysical sense when one considers that the submarine area of the chain far exceeds the subaerial area and that the effort expended on the land area to date is almost infinitely greater than that devoted to study of the submarine area.

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The Inshore Fish Fauna of Johnston Island, a Central Pacific Atoll[1]

WILLIAM A. GOSLINE[2]

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The Inshore Fish Fauna of Johnston Island, a Central Pacific Atoll[1]

WILLIAM A. GOSLINE[2]

INTRODUCTION

THIS PAPER is primarily concerned with Central Pacific zoogeography. Its main purpose is to trace in so far as possible the derivation and the immigration and emigration routes of the Johnston Island inshore fish fauna. The importance of Johnston for a study of this sort lies in its position between the areas inhabited by the great tropical Pacific fauna to the south and the strongly endemic Hawaiian fauna to the north (Fig. 1).

The first section of this paper records the fishes known from Johnston and presents the taxonomic interpretations upon which the zoogeographic treatment of the second section is based.

Of the collections dealt with, the most important for this paper are those taken by V. E. Brock, Y. Yamaguchi, and the author at Johnston in February 1951. These collections were made possible through the kindness of Colonel Cronau, then commanding officer of the island, and were greatly facilitated by Lt. Col. Eaton and other members of the airforce who were there at the time. In addition, three small collections from the same island were turned over to me by Brock, Schaefer, and Francis respectively. Finally, a reexamination of certain fishes from Johnston recorded by Fowler and Ball (1925) was made possible through the courtesy of the staff of the Bernice P. Bishop Museum.

SECTION 1. FISHES RECORDED FROM JOHNSTON ISLAND

Except for Schultz's (1950: 548) reference to *Cirrhitus alternatus*, the following four works include or cite all of the published records on Johnston fishes.

Smith and Swain (1882) recorded 27 species from the island, 5 of which they described as new.

Fowler and Ball (1925) listed 72 species from Johnston collected by the "Tanager" Expedition of 1923. One of these was described as new.

Schultz and collaborators (1953) in the first volume of their report on "Fishes of the Marshall and Marianas Islands" recorded specimens of about 9 Johnston species. Most of these were referred to only in passing, e.g., in tables; three, however, were described as new.

Halstead and Bunker (1954), in a report on fish poisoning at Johnston Island, listed 60 species investigated.

One hundred and eighteen species of Johnston fishes have been seen by the present author. Species recorded from the island that have not been seen are marked in the species accounts with an asterisk; some of these almost certainly represent misidentifications and others equally certainly do not, but any attempt to decide which are which would only lead to further misidentifications.

It is easy to criticize others for recording species without also providing sufficient descriptive material to determine whether the record has been correctly identified. It is more

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[1] Contribution No. 73, Hawaii Marine Laboratory. Manuscript received March 18, 1955.

[2] Department of Zoology and Entomology, University of Hawaii.

difficult to write a paper that does not commit the same error and is still sufficiently brief to be publishable. The present account attempts a compromise between these two pitfalls. Species which are sufficiently distinct to be readily recognizable, about which there are at present no zoological or nomenclatorial questions, and whose presence at Johnston there is no zoogeographic reason to doubt, have been recorded by name only. For the others an attempt has been made to give the diagnostic characters of the Johnston specimens on the basis of which the species identification was made. It is clearly recognized that this method only alleviates, and by no means eliminates, the faults of recording species by name only.

This section contains notes on the classification of certain species of *Uropterygius*, *Belone*, *Pseudamiops*, *Scarus*, and *Scorpaena* as well as the records of Johnston fishes. Families are listed in "phylogenetic sequence"; genera and species within the family are taken up alphabetically. Identifications and nomenclature follow Schultz, *et al.* (*op. cit.*) where possible, and various authors for the remaining species. All lengths given in millimeters are standard lengths; total lengths are expressed in inches.

MYLIOBATIDAE

***Aetobatus narinari** (Euphrasen)

Fowler and Ball, 1925, 1 spec.; Halstead and Bunker, 1954, 1 spec.

SYNODONTIDAE

Saurida gracilis (Quoy and Gaimard)

5 specs., 69–110 mm., 1951; 1 spec., Brock, 1948.

A double band of teeth on each side of the palate; inner rays of pelvic fins contained about 1.2 times in the length of the outermost rays.

Synodus binotatus Schultz

3 specs., 46–77 mm., 1951.

A single row of teeth on each side of palate; three and a half scale rows between the lateral line and the dorsal origin; peritoneum pale; no black spot on opercle but a dark mark on tip of snout and three dark rings on the back behind the dorsal fin; 9 anal rays; tips of first dorsal rays not reaching tips of succeeding rays when the fin is depressed; dorsal origin equidistant from tip of snout and origin of adipose; tips of central caudal rays not black (cf., Schultz, *et al.*, 1953: 30, 31).

CONGRIDAE

Conger noordziekii Bleeker

1 spec., 255 mm., 1951.

Origin of dorsal over anterior third of the depressed pectorals; a dark longitudinal line extending below and behind eye.

OPHICHTHIDAE

Brachysomophis sauropsis Schultz

1 spec., 362 mm., 1951.

As compared with a 1070 mm. specimen of *Brachysomophis henshawi* from Hawaii, the Johnston specimen differs in having the distance from the tip of snout to the posterior border of the eye contained 9 times in the head length to gill openings instead of 7.2 times, in having the dorsal and anal fins low (the anal does not even extend above the groove that encloses it) and light in coloration instead of well-developed and with the dorsal black-based; in having the pores of the head and body not enclosed in dark areas; and in having no dark bands either along the mid-dorsal line or along the lateral line area of the sides. The Johnston specimen agrees in every way with Schultz's original description of *Brachysomophis sauropsis*.

Leiuranus semicinctus (Lay and Bennett)

6 specs., 133–227 mm., 1951. Fowler and Ball, 1925, 3 specs.

Ovate black saddles about equal in maximum width to the interspaces between them.

Leptenchelys labialis (Seale)

2 specs., 121–134 mm., 1951.

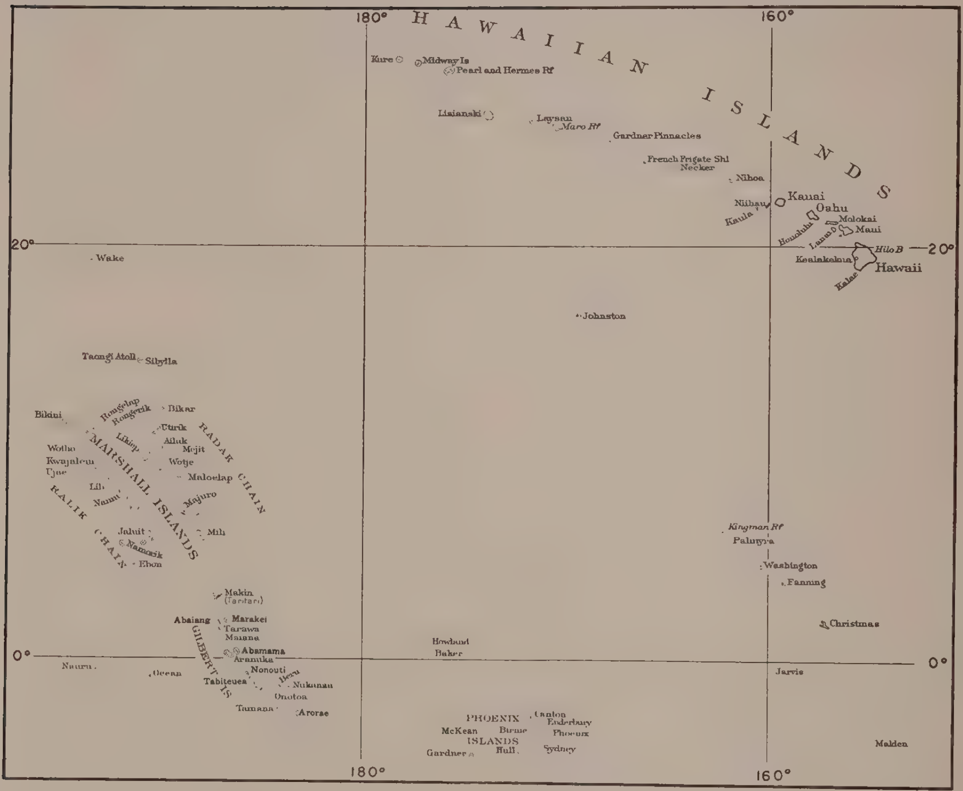
HAWAIIAN ISLANDS
180°
160°
Kure
Midway Is
Pearl and Hermes Rf
Lisianski
Laysan
Maro Rf
Gardner Pinnacles
French Frigate Shl
Necker
Nihoa
Niihau
Kaula
Kauai
Oahu
Honolulu
Molokai
Lanai
Maui
Hilo B
Kealakekua
Hawaii
Kalae
20°
Wake
Johnston
Taongi Atoll
Sibylla
Bikini
Rongelap
Rongerik
Bikar
Utirik
Likiep
Ailuk
Mejit
Wotho
Kwajalein
Ujae
Wotje
Maloelap
Lib
Namu
Majuro
RADAK CHAIN
MARSHALL ISLANDS
RALIK CHAIN
Jaluit
Namorik
Ebon
Mili
Makin
(Taritari)
Abaiang
Marakei
Tarawa
Maiana
Abamama
Aranuka
Nonouti
Beru
Nukunau
Tabiteuea
Onotoa
Tamana
Arorae
GILBERT IS
0°
Nauru
Ocean
Howland
Baker
Kingman Rf
Palmyra
Washington
Fanning
Christmas
Jarvis
PHOENIX ISLANDS
Canton
Enderbury
McKean
Birnie
Phoenix
Gardner
Hull
Sydney
Malden
180°
160°
0°

FIG. 1. Chart of the region surrounding Johnston Island. From U. S. Hydrographic Chart 1500, 47th edition.

Ventral surface of snout with a median groove that contains teeth; caudal fin well developed; dorsal origin a little over a head length behind head (cf., Schultz, *et al.*, 1953: 71).

I have dealt elsewhere (1950: 312–314; 1952: 300–306) at some length with the reasons why *Leptenchelys*, *Muraenichthys*, and *Schultzidia* should be placed in the Ophichthidae.

Muraenichthys cookei Fowler

12 specs., 103–173 mm., 1951.

Posterior rim of orbit about over rictus; dorsal origin from 2 to 5 eye diameters ahead of anus; vomerine teeth uniserial (cf., Schultz, *et al.*, 1953: 71, 72).

These specimens are discussed in section 2.

Muraenichthys gymnotus Bleeker

3 specs., 52–118 mm., 1951.

Dorsal fin originating about half a head length behind the anus; rear margin of eye slightly ahead of rictus; teeth on front of maxillary and dentary at least double-rowed; snout sharp, the distance from its tip to the rictus contained about 3.7 times in the head length (cf., Schultz, *et al.*, 1953: 71–73).

Muraenichthys schultzei Bleeker

3 specs., 106–117 mm., 1951. Fowler and Ball, 1925, 12 specs.

Dorsal origin about two-thirds of a head length behind anus; snout bluntly rounded; vomerine teeth two-rowed (cf., Schultz, *et al.*, 1953: 71–73).

Myrichthys bleekeri Gosline

1 spec., 365 mm., 1951. As *Myrichthys colubrinus*, Fowler and Ball, 1925, 12 specs.

Width of black band over gill opening contained two times in the white interspace behind it; only the last two bands completely encircling the body.

Myrichthys maculosus (Cuvier)

5 specs., 275–865 mm., 1951. Fowler and Ball, 1925, 1 spec. As *Myrichthys stypurus* Smith and Swain, 1882, 1 spec.

Round black spots on a greenish background.

Schultzidia johnstonensis (Schultz and Woods)

2 specs., 101–167 mm., 1951. Schultz, *et al.*, 1953, 1 spec.

Maxillary teeth small, in several rows, facing inward; vomerine teeth minute in the small specimen, apparently absent in the larger; no median papilla on upper lip between nostrils (cf., Schultz, *et al.*, 1953: 71).

MORINGUIDAE

Moringua macrochir Bleeker

5 specs., 128–262 mm., 1951.

Lower jaw projecting; lateral line pores 98–110.

The name used for this species follows Gosline and Strasburg (In press).

MURAENIDAE

Anarchias allardicei Jordan and Starks

5 specs., 121–135 mm., 1951.

Pore near posterior nostril lying somewhat ahead of nostril; body color plain brown, the brownish color provided by microscopic brown speckling on a light background (cf., Schultz, *et al.*, 1953: 139).

Anarchias cantonensis (Schultz)

3 specs., 142–163 mm., 1951.

Pore near posterior nostril lying somewhat ahead of nostril; body with a reticulate pattern of dark on light; chin barred (cf., Schultz, *et al.*, 1953: 139).

Anarchias leucurus (Snyder)

35 specs., 103–176 mm., 1951.

Pore near posterior nostril lying slightly behind nostril; body with a reticulate pattern; chin barred (cf., Schultz, *et al.*, 1953: 139).

Echidna leucotaenia Schultz

5 specs., 150–240 mm., 1951.

Body plain brown; fins black-based and white-edged; lower jaw light except for a brown patch below each eye (cf., Schultz, *et al.*, 1953: 100).

Echidna polyzona (Richardson)

1 spec., 63 mm., 1951.

Pebble-like teeth on vomer; about 27 dark bands on body (cf., Schultz, *et al.*, 1953: 100).

Echidna zebra (Shaw)

1 spec., 850 mm., 1951.

Anus well behind middle of body length; black and white stripes on body (cf., Schultz, *et al.*, 1953: 100).

***Gymnothorax buroensis** Bleeker

Halstead and Bunker, 1954, 5 specs. It seems most likely that Halstead and Bunker's record refers to *Gymnothorax eurostus*, the Hawaiian form of *G. buroensis*. Indeed, since none of the Hawaiian "endemic" species are recorded by Halstead and Bunker, such of this element in the Johnston fauna as was taken by these authors must have been misidentified.

Gymnothorax eurostus (Abbott)

20 specs., 158–500 mm., 1951.

Premaxillary teeth divisible into 5 series, these somewhat difficult to distinguish in large specimens; no black blotch surrounding gill opening; body mottled (cf., Schultz, *et al.*, 1953: 109).

These specimens are dealt with in section 2.

Gymnothorax gracilicaudus Jenkins

3 specs., 106–140 mm., 1951.

Teeth not serrate, in three series on premaxillary, those of the median row notably enlarged. Body light with irregular dark vertical bands; no black blotch around gill opening; a prominent white band down the midline of the snout; median fins with broad, plain, light borders; dark pigment forming an irregular band extending from behind eye across rictus; chin and abdomen light; a dark saddle running across top of head and down at least to the level of the eye on either side.

***Gymnothorax javanicus** (Bleeker)

Halstead and Bunker, 1954, 2 specs.

Gymnothorax meleagris (Shaw)

3 specs., 230–670 mm., 1951. Fowler and Ball, 1925, 2 specs.; Halstead and Bunker, 1954, 2 specs.

Five rows of teeth on premaxillary; gill opening in a black area; small, round, white spots on a dark ground.

Gymnothorax moluccensis (Bleeker)

1 spec., 257 mm., 1951.

Larger, lateral teeth in both jaws serrate. Body plain brown (cf., Schultz, *et al.*, 1953: 109).

Gymnothorax pictus (Ahl)

As *Lycodontis picta*, Fowler and Ball, 1925, 2 specs., one of these reexamined.

Gymnothorax undulatus (Lacépède)

2 specs., 250 and 850 mm., 1951.

Premaxillary teeth in three series, the central teeth fang-like. Body dark, with narrow white reticulations forming irregular vertical lines; no white streak on snout (cf., Schultz, *et al.*, 1953: 109–113).

Rabula fuscomaculata Schultz

19 specs., 116–149 mm., 1951. Schultz, *et al.*, 1953, 16 specs.

Dorsal fin commencing somewhat less than a head length ahead of anus; dark spots and reticulations on a light ground (cf., Schultz, *et al.*, 1953: 139).

Uropterygius dentatus Schultz

1 spec., 366 mm., 1951. Schultz, *et al.*, 1953, 373 mm., holotype.

Mottled with dark spots, those posteriorly more or less united into irregular vertical bars; vomerine teeth either absent or made up of a short posterior continuation of the median premaxillary row; both anterior and posterior nostrils pigmented though less so than the rest of the head; gill opening high on the sides.

This specimen seems to be more or less intermediate between *U. dentatus* and *U. supraforatus*. Indeed the distinctions between these two species as given by Schultz (in Schultz, *et al.*, 1953: 141) do not seem to be very clear-cut. Nevertheless, it seems best to follow Schultz in recognizing the Johnston form as *U. dentatus*, at least until such time as specimens of *U. supraforatus* become available for comparison.

For the relationships between *U. dentatus* and *U. fuscoguttatus*, see the account of the latter species.

Uropterygius fuscoguttatus Schultz

3 specs., 129–152 mm., 1951. Schultz, *et al.*, 1953, 1 spec.

At the present time there seem to be three recognized Central Pacific species in the *Uropterygius* group with the gill openings high on the sides and multiserial teeth in both jaws: *U. supraforatus* Regan, *U. dentatus* Schultz, and *U. fuscoguttatus* Schultz. Unfortunately, Schultz has placed his two species, both of which according to specimens and his own figures (in Schultz, *et al.*, 1953: figs. 32, 33) have the gill opening about equally high on the sides, on opposite sides of a major break in his key based on the level of the gill openings. Actually *U. fuscoguttatus* is rather difficult to distinguish from *U. supraforatus* and *U. dentatus*. As compared with these, *U. fuscoguttatus*, judging from Hawaii and Johnston material, is a relatively small species, not attaining a length of over 285 mm. A female 185 mm. is ripe. From *U. dentatus* it can best be distinguished by coloration: *U. dentatus* is an eel with dark spotting and mottling everywhere; *U. fuscoguttatus*, by contrast, is spotted and mottled posteriorly, but the head and forepart of body are plain brown, the brownish color made up of minute, regularly spaced punctulations. In addition *U. fuscoguttatus* has a somewhat longer snout; the distance between the posterior margin of the eye and the most posterior maxillary tooth is considerably less than the distance from the tip of the snout to the posterior nostril (in *U. dentatus* these two distances are about equal). In *U. dentatus* the two jaws are about equal, and the distance from the tip of chin to the most posterior mandibular tooth is contained about 2.4 times in the head length; in *U. fuscoguttatus* the lower jaw is very slightly inferior, and the distance from the tip of the chin to the last mandibular tooth is contained about 2.7 times in the head length. There are also many more teeth in *U. dentatus* than in *U. fuscoguttatus* but since the teeth are multiserial in both species, this difference is difficult to quantify. The features listed above would be adequate for distinguishing the two species if they were the same size. Unfortunately they are not. The largest known specimen of *U. fuscoguttatus* is one from Hawaii measuring 285 mm.; the smallest of the three known specimens of *U. dentatus* is 363 mm.

Uropterygius polyspilus Regan

2 specs., 150 and 180 mm., 1951.

Anus very slightly behind middle of the total length; prominent, roundish dark spots on a light brown background; tip of snout white in alcohol, yellow in life.

Uropterygius tigrinus (Lesson)

2 specs., 670 and 680 mm., 1951. As *Gymnomuraena tigrina*, Smith and Swain, 1882, 1 spec.

Anus far behind middle of total length; prominent, roundish dark spots on a light brown background; snout of the same color as the rest of the body but speckled rather than spotted.

BELONIDAE

Belone platyura Bennett

1 spec., 295 mm., 1951. Halstead and Bunker, 1954, 1 spec. As *Belone persimilis*, Schultz, *et al*., 1953, 4 specs.

The relationship between *Belone platyura* and *B. persimilis* needs clarification. *B. persimilis* was first differentiated from *B. platyura* by Günther (1909: 340, text fig.) on the basis of the smaller eye. In order to demonstrate this, Günther compared the eye size with the interorbital and with the postorbital head length in the two species (Table 1). In 1943 Schultz (p. 54) placed *B. persimilis* in the synonymy of *B. platyura*, stating: "After measuring a large series of specimens of the large-eyed form *B. platyura* and many of the small-eyed form named by Günther *B. persimilis*, I am of the opinion that when small this species has a small eye and when larger the eye is much larger in proportion." In 1953 Schultz (p. 160) reseparated the two nominal species on the basis of eye size and the relatively shorter postorbital head length of *B. persimilis*. He compared these two characters with one another and each of them with the distance between the pelvic insertion and the anal origin in the two species (Table 1). Whereas Günther believed the two species occurred together over a wide area, Schultz (1953, *loc. cit.*) considered all of his Marshallese material to represent *B. platyura* and all of the Johnston (and by inference Hawaiian) specimens to be *B. persimilis*.

Counts and measurements of the six specimens available to me are given in Table 1. Aside from the characters listed, an attempt was made to find others which might be used for differentiating two species. For example, the length of the anal base was compared with the postanal length, but it was found that this comparison merely demonstrated the difference in the number of anal rays. Again, the Johnston and the larger Hawaiian specimen at present lack cheek scales whereas the other four have such scales, but this may be an artifact of preservation. At first it was thought possible to separate a long, narrow-headed species from one with a relatively short and broad head (the smaller Hawaiian and the

TABLE 1

CERTAIN COUNTS, MEASUREMENTS, AND DIFFERENCES BETWEEN *Belone persimilis?* AND *Belone platyura*
Measurements, except the first, are given in thousandths of the body length as defined

	Belone persimilis?			*Belone platyura*		
	Oahu	Oahu	Johnston	Gilberts	Gilberts	Bikini
Body length, from front of eye to tip of fleshy projection on middle caudal rays	255 mm.	272 mm.	299 mm.	230 mm.	278 mm.	297 mm.
Distance from front of nasal bones to anterior nostril	35.3	34.5	36.8	33.3	38.1	36.4
Horizontal orbit diameter	45.2	45.0	44.2	46.1	47.8	50.2
Postorbital head length	76.2	76.8	73.4	81.3	82.8	77.7
Width of skull in front of eye	51.1	50.9	51.2	46.5	56.8	57.2
Width of bony interorbital	36.5	37.0	34.5	39.1	43.8	43.1
Maximum width of skull across pterotics	52.5	53.7	53.2	45.9	62.2	62.3
Distance from pelvic insertion to anal origin	184	182	181	189	192	174
Dorsal rays	14	14	14	13	14	14
Anal rays	18	19	19	17	18	18
Pectoral rays	12	12	12	12	12	12
Orbit into bony interorbital:						
Present data	0.81 to 1.1			0.85 to 0.92		
According to Günther (1909)	less than (soft?) interorbital			equals (soft?) interorbital		
Orbit into postorbital head:						
Present data	1.67 to 1.70			1.55 to 1.75		
According to Günther (1909)	1.6 to 2			1.5 to 1.67		
According to Schultz (1953)	1.8 to 2.1			1.5 to 1.8		
Orbit into pelvic-anal distance						
Present data	4.1 to 4.2			3.5 to 4.1		
According to Schultz (1953)	4.0 to 5.1			3.1 to 3.6		
Postorbital head length into pelvic-anal distance:						
Present data	2.3 to 2.5			2.2 to 2.3		
According to Schultz (1953)	2.3 to 2.5			2.0 to 2.2		

smaller Gilbertese specimen would constitute the narrow-headed form) but this idea was discarded. In the final analysis it appears that if any separation of two species among the tabulated specimens is made, it should be based on the size of the eye. However, the difference in eye size between the specimens in Table 1 labelled *B. persimilis?* and those labelled *B. platyura* is very slight, and from the Table it is obvious that to state this difference in relation to the interorbital width, the postorbital head length, and only to a lesser extent the pelvic-anal distance obscures rather than clarifies the segregation of two forms. In short, of the characters used by Günther and by Schultz (1953), only two of them will serve to separate the specimens at hand, and even in these there may prove to be more of a continuous distribution than a separation. Under the circumstances it seems that a convincing means of differentiating *B. persimilis* from *B. platyura*, if both species are valid, remains to be demonstrated; meanwhile there is little practical use in recognizing them. Finally, if the two prove valid, then the nomenclatorial question will arise as to whether the second should be called *B. persimilis*, *B. carinata* (described from the Hawaiian Islands by Cuvier and Valenciennes in 1846), or perhaps by some other early name.

HEMIRAMPHIDAE

Hyporhamphus acutus (Günther)
2 specs., 80 and 163 mm., 1951.

Upper jaw scaled; greatest diameter of the nasal fossa about one third the diameter of the orbit; posterolateral border of fossa with a prominent bony rim; sensory pore on preorbital apparently branched above with a pore in front of eye and another near nasal fossa; inner pelvic ray not elongate. Dorsal base very slightly shorter than base of anal; dorsal with 14 rays, anal with 18 in larger specimen.

The identification of these specimens seems certain, except that the small diameter of the nasal fossa throws them into the genus *Hemiramphus* according to Schultz and Woods' generic key (in Schultz, *et al.*, 1953: 166). Measurement of other available specimens of the same species including Bikini duplicates indicates that the key character referred to will not serve for this species.

EXOCOETIDAE

***Cypselurus poecilopterus** (Valenciennes)
Fowler and Ball, 1925, 2 specs.

***Cypselurus simus** (Valenciennes)
Fowler and Ball, 1925, 1 spec.

AULOSTOMIDAE

***Aulostomus chinensis** (Linnaeus)
Smith and Swain, 1882, 1 spec.; Halstead and Bunker, 1954, 5 specs.

FISTULARIIDAE

Fistularia petimba Lacepède
1 spec., 900 mm., 1951. Fowler and Ball, 1925, 1 spec.

HOLOCENTRIDAE

Holocentrus lacteoguttatus Cuvier
10 specs., 54–109 mm., 1951; 2 specs., 97 and 101 mm., Brock, 1948. Fowler and Ball, 1925, 5 specs.; Halstead and Bunker, 1954, 2 specs.

The two opercular spines subequal in size; body speckled with sooty marks.

Holocentrus microstomus Günther
Fowler and Ball, 1925, 2 specs., one of these reexamined.

Dorsal XI–12; perforated scales in lateral line 48; longest anal spine reaching beyond caudal base.

Holocentrus sammara (Forskål)
3 specs., 117–157 mm., 1951. Halstead and Bunker, 1954, 1 spec.

Brown spotting on a bronze to silvery background; a large dark blotch on the spinous dorsal.

Holocentrus spinifer (Forskål)
4 specs., 151–300 mm., 1951; 1 spec., 261 mm., Schaefer, 1948. Fowler and Ball, 1925, 6 specs.; Halstead and Bunker, 1954, 7 specs. As *Holocentrus leo*, Smith and Swain, 1882, 2 specs.

Holocentrus tiere Cuvier and Valenciennes
8 specs., 121–226 mm., 1951. Halstead and Bunker, 1954, 3 specs. As *Holocentrus erythraeus*, Smith and Swain, 1882, 2 specs.

Perforated scales in the lateral line 50; maxillary longer than eye; dorsal XI–14.

Holotrachys lima (Valenciennes)
1 spec., 115 mm., 1951.

Myripristis argyromus Jordan and Evermann
31 specs., 45–210 mm., 1951; 1 spec., 121 mm., Brock, 1948. Halstead and Bunker, 1954, 3 specs. As *Myripristis murdjan*, Fowler and Ball, 1925, 1 spec., this specimen reexamined.

Perforated scales in the lateral line 34; anal IV, 13; gill rakers $12 + 1 + 25 = 38$; interorbital width contained about 3.7 times in the head length.

***Myripristis berndti** Jordan and Evermann
Halstead and Bunker, 1954, 1 spec.

APOGONIDAE

Apogon erythrinus Snyder
15 specs., 30–42 mm., 1951.

Dorsal VI–I, 9; anterior margin of preopercle smooth; anal II, 8; lateral line complete; second spine of first dorsal much longer than third (cf., Lachner, *in* Schultz, *et al.*, 1953: 435).

Apogon menesemus Jenkins

13 specs., 67–128 mm., 1951; 1 spec., 86 mm., Brock, 1948.

Dorsal VII–I, 9; both margins of preopercle serrate; palatine teeth absent; gill rakers (including rudiments) 4 + 1 + 17 = 22; black pigmentation on caudal forming a complete arc.

Apogon snyderi Jordan and Evermann

31 specs., 32–100 mm., 1951; 2 specs., 40 and 97 mm., Brock, 1948. As *Apogon frenatus*, at least in part, Fowler and Ball, 1925, 6 specs.

Dorsal VII–I, 9; both margins of preopercle serrate; palatine teeth present; gill rakers (including rudiments) 4 + 1 + 13 = 18; no circular spot at midbase of caudal fin in specimens over 55 mm. but instead a dark bar that covers the whole fin base; in specimens 50–55 mm. a more or less well-delimited, round dark spot that lies above but touches the lateral line; stripe on sides not well-marked, absent in large specimens; serrations on anterior margin of preopercle reaching a larger size than those on posterior margin; suborbital serrations few in small specimens, numerous in large, but almost always more than 3 (cf., Lachner, in Schultz, *et al.*, 1953: 436, 437).

Apogon waikiki (Jordan and Evermann)

3 specs., 21–36 mm., 1951.

Dorsal VII–I, 9; no serrations on preopercle; palate toothless; lateral line complete; dorsal fin without ocellus; dorsal rounded, dusky at base, the tips of the outer rays white.

Pseudamiops gracilicauda (Lachner)

1 spec., 23 mm., 1951.

Recently Smith (1954) has described the new genus *Pseudamiops* for the single new species *P. pellucidus*. In the same article (p. 794) he erects the "provisional" genus *Lachneria* for the species *Gymnapogon gracilicauda* Lachner. The difference between the two genera according to the descriptions is that *Pseudamiops* is scaled and the specimens on which *Gymnapogon gracilicauda* was based were naked. Smith suspected that the scales of *G. gracilicauda* had been rubbed off; hence the provisional nature of his genus *Lachneria*. The specimen from Johnston plus two Hawaiian specimens agree well with Lachner's description of *Gymnapogon gracilicauda* except that they are more or less scaled. However, as with *Pseudamiops pellucidus*, the scales are apparently highly deciduous, for none of the three specimens are now completely scaled.

The chief points, aside from squamation, in which the Johnston and Hawaii specimens differ from Lachner's description and figure (in Schultz, *et al.*, 1953: 497, 498, fig. 84) are the following. The present specimens have a very pinched-in abdominal region as though the fishes had been starving; the specimen figured by Lachner does not have this feature, nor does that of *Pseudamiops* figured by Smith. The longest spine of the anal and that of the second dorsal are about half the length of the succeeding soft ray, instead of about four fifths the length of these rays as shown in Lachner's figure. The middle pectoral rays terminate in elongate, soft, fragile filaments. There seem to be at most 6 or 7 teeth on the vomer instead of about 20 according to Lachner (the vomerine teeth of *Pseudamiops* are reduced to one or two). There are no weak spines on the operculum; two are said to be present in *Gymnapogon gracilicauda*. Finally, only one of the three specimens has the system of papillae on the head well developed; however, as Smith has noted the prominence of this character probably varies with the nature of preservation.

From *Pseudamiops pellucidus* the Hawaiian and Johnston specimens differ in having one fewer soft anal ray and in lacking the pigment spots on the head.

It may prove to be that the Hawaiian and Johnston material is a separate species from both Lachner's Marshallese form and Smith's from Africa. However, as Lachner's material was in poor condition it will apparently require comparison with better Marshallese material to determine whether the Hawaiian form is conspecific with it or not.

No such doubt seems possible regarding the necessity of placing the genus *Lachneria* in the synonymy of *Pseudamiops*.

KUHLIIDAE

Kuhlia marginata (Cuvier and Valenciennes)

9 specs., 61–221 mm., 1951. As *Kuhlia taeniura*, Smith and Swain, 1882, 2 specs.

These specimens will be dealt with in section 2.

PSEUDOCHROMIDAE

Pseudogramma polyacantha (Bleeker)

11 specs., 39–74 mm., 1951; 4 specs., 35–51 mm., Brock, 1948.

Dorsal spines VII; no enlarged pores between the eyes.

PRIACANTHIDAE

Priacanthus cruentatus (Lacepède)

2 specs., 127 and 140 mm., 1951; 4 specs., 89–93 mm., Francis, 1948. Halstead and Bunker, 1954, 2 specs.

Soft dorsal rays 13; soft anal rays 14; no dark spots on pelvic fins; caudal fin truncate.

SERRANIDAE

***Pristipomoides sieboldii**

Fowler and Ball, 1925, 1 spec.

KYPHOSIDAE

***Kyphosus bigibbus** Lacepède

Halstead and Bunker, 1954, 1 spec.

Kyphosus vaigiensis (Quoy and Gaimard)

1 spec., 170 mm., 1951.

Longest dorsal spine longer than longest soft dorsal ray; dorsal XI, 13; anal III, 12 or 13; greatest depth 2.3 in standard length.

MULLIDAE

***Mulloidichthys auriflamma** (Forskål)

Halstead and Bunker, 1954, 2 specs. As *Upeneus vanicolensis*, Smith and Swain, 1882, 1 spec. As *Mulloides auriflamma* Fowler and Ball, 1925, 4 specs.

Mulloidichthys samoensis (Günther)

5 specs., 162–219 mm., 1951; 6 specs., 92–101 mm., Francis, 1948; 9 specs., 124–143 mm., Schaefer, 1948. Halstead and Bunker, 1954, 7 specs. As *Upeneus preorbitalis* Smith and Swain, 1882, 1 spec.

A black spot on sides below spinous dorsal; a dark area on inside of gill cover ahead of pseudobranch.

Parupeneus barberinus (Lacepède)

As *Upeneus barberinus*, Fowler and Ball, 1925, 1 spec., this reexamined.

Parupeneus bifasciatus (Lacepède)

8 specs., 53–210 mm., 1951. Halstead and Bunker, 1954, 3 specs. As *Parupeneus crassilabris*, Smith and Swain, 1882.

Depth of body greater than the head length; barbels short, failing to reach the pelvic bases by about three and a half scales; body usually with vertical dark bands, one of these with its anterior border about even with a line drawn between the soft dorsal and anal origins.

***Parupeneus chryserydros** (Lacepède)

Halstead and Bunker, 1954, 2 specs. As *Upeneus chryserydros*, Fowler and Ball, 1925, 1 spec.

***Parupeneus crassilabris** (Valenciennes)

Halstead and Bunker, 1954, 1 spec.

Parupeneus multifasciatus (Quoy and Gaimard)

3 specs., 175–220 mm., 1951. As *Upeneus velifer* Smith and Swain, 1882, 1 spec.

Depth of body less than the head length; barbels long, failing to reach the pelvic origins by 1 scale; body with dark vertical blotches, one of these with its anterior border extending downward and forward from the last ray of the first dorsal.

***Parupeneus trifasciatus** (Lacepède)

Halstead and Bunker, 1954, 4 specs.

CIRRHITIDAE

Cirrhitus alternatus Gill

1 spec., 72 mm., 1951; 1 spec., 119 mm., Brock, 1948. As *Cirrhitus maculatus*, Fowler and Ball, 1925, 1 spec.

These specimens are dealt with in section 2.

Paracirrhites bimacula (Jenkins)

13 specs., 28–60 mm., 1951.

CARANGIDAE

Carangoides ferdau jordani Nichols

1 spec., 318 mm., 1951. Halstead and Bunker, 1954, 5 specs.

Teeth in bands in both jaws; breast naked; depth of body about 2.8 in standard length; anal soft rays 25; 20 gill rakers on lower portion of first arch (cf., Woods, in Schultz, *et al.*, 1953: 505).

***Caranx ascensionis** (Osbeck)

Fowler and Ball, 1925, 4 specs.

***Caranx dasson** Jordan and Snyder

Fowler and Ball, 1925, 1 spec.

***Caranx gymnostethoides** (Bleeker)

Smith and Swain, 1882, 1 spec.

***Caranx lugubris** Poey

Halstead and Bunker, 1954, 5 specs.

***Caranx melampygus** Cuvier

Halstead and Bunker, 1954, 4 specs.

***Scomberoides sancti-petri** (Cuvier)

Smith and Swain, 1882, 1 spec.; Fowler and Ball, 1925, 2 specs.

Trachurops crumenophthalmus (Bloch)

1 spec., 286 mm., 1951; 4 specs., 121–128 mm., Francis, 1948; 2 specs., 173 and 177 mm., Schaefer, 1948.

Shoulder girdle deeply furrowed.

POMACENTRIDAE

Abudefduf imparipennis (Vaillant and Sauvage)

20 specs., 33–50 mm., 1951. Fowler and Ball, 1925, 4 specs.

Preopercle smooth; teeth flattened at tips; dorsal XII, 15; color plain yellowish green; upper base of pectoral pale.

Abudefduf phoenixensis Schultz

2 specs., 50–51 mm., 1951. As *Abudefduf albofasciatus*, Fowler and Ball, 1925, 2 specs.

Preopercle smooth; teeth somewhat flattened at tips; dorsal XII, 18; anal II, 13; caudal peduncle encircled by a black band, followed abruptly by white on the remainder of the caudal peduncle and tail; a round black spot on the soft dorsal.

***Abudefduf sordidus** (Forskål)

Fowler and Ball, 1925, 8 specs.; Halstead and Bunker, 1954, 7 specs.

Chromis leucurus Gilbert

2 specs., 61 and 65 mm., 1951; 1 spec., 68 mm., Brock, 1948. As *Chromis dimidiatus*, Fowler and Ball, 1925, 1 spec., 64 mm., this specimen reexamined.

This species is described herewith.

After much vacillation, these plain brown-bodied specimens with a black blotch at the pectoral base are here identified as a color

TABLE 2

CERTAIN COUNTS FOR TWO FORMS OF *Chromis leucurus*

FORM	LATERAL LINE SCALES			TOTAL GILL RAKERS					SOFT DORSAL RAYS			SOFT ANAL RAYS			PECTORAL RAYS		
	15	16	17	27	28	29	30	31	12	13	14	12	13	14	16	17	18
Black and white	2	3		1	2	1	1		2	14	2	2	12	4	1	4	
Plain brown	3	2	1	1	2			2		8		1	7		1	2	2

form of the black and white *Chromis leucurus*. Comparison of the same two forms from Hawaiian material provides the following information: (1) the black and white and the brown specimens differ little in morphological features or in counts (Table 2); (2) ripe individuals of both sexes occur in both color forms; and (3), though the two color forms overlap in size ranges, the plain brown form is represented only by specimens 47 to 70 mm. in standard length, whereas black and white specimens range from 17 to 57 mm. In life both forms may be seen over the same coral head. Presumably the brown form represents an ontogenetic color change that occurs after maturity has been attained.

Chromis vanderbilti (Fowler)

1 spec., 35 mm., 1951.

This specimen differs from Hawaiian and Wake Island material in lacking the black on the lower caudal lobe. There appear to be no other differences. Dorsal XII, 11; anal II, 11, the anterior two-thirds black, becoming abruptly light posteriorly.

Dascyllus albisella Gill

12 specs. 43–88 mm., 1951; 2 specs., 69–75 mm., Brock, 1948.

Though no specimens of *Dascyllus trimaculatus* are readily available, the Hawaiian form seems to differ, among other features, in having more dorsal and anal soft rays. The present (1951) specimens agree with the Hawaiian form in having 15 dorsal soft rays in two specimens and 16 in ten, 14 soft rays in the anal of one specimen, and 15 in the anal of eleven.

*__Dascyllus marginatus__ (Rüppell)

Halstead and Bunker, 1954, 4 specs.

Plectroglyphidodon johnstonianus Fowler

8 specs., 27–80 mm., 1951. Fowler and Ball, 1925, 1 spec. As *Abudefduf johnstonianus*, Halstead and Bunker, 1954, 1 spec.

Lips plicate; dorsal XII, 18; anal II, 16 or 17.

LABRIDAE

*__Bodianus bilunulatus__ (Lacepède)

As *Harpe bilunulata*, Smith and Swain, 1882, 1 spec.

Cheilinus rhodochrous Günther

3 specs., 146–205 mm., 1951. Halstead and Bunker, 1954, 5 specs. As *Cheilinus digramma*, Smith and Swain, 1882, 3 specs., and Fowler and Ball, 1925, 1 spec.

The 1951 specimens have the elongate head, white band on the caudal peduncle, and IX dorsal spines that seem to characterize this species. No black lines radiating downward from eye.

Epibulus insidiator (Pallas)

9 specs., 73–255 mm., 1951. Fowler and Ball, 1925, 2 specs.; Halstead and Bunker, 1954, 4 specs.

Lower jaw extending backward to isthmus.

*__Gomphosus tricolor__ Quoy and Gaimard

Fowler and Ball, 1925, 2 specs.

Gomphosus varius Lacepède

16 specs., 27–106 mm., 1951; 4 specs., 27–89 mm., Brock, 1948.

A dark stripe through eye; vertical fins dark.

Halichoeres ornatissimus (Garrett)

1 spec., 58 mm., 1951. Fowler and Ball, 1925, 2 specs., these reexamined.

These specimens all have the characteristic dark mark just behind the eye.

Novaculichthys taeniourus (Lacepède)

1 spec., 119 mm., 1951.

Only four lines radiating out from the eye.

Pseudocheilinus sp.

12 specs., 30–55 mm., 2 specs., 40–46 mm., Brock, 1948.

First dorsal rays usually produced into elongate filaments; two longitudinal scale rows on cheek below eye; three or four black longitudinal lines along upper sides; background color of body bluish; 16 rays in the pectoral counting the splint above; no black dot on the caudal peduncle above.

This species will be described elsewhere by Dr. L. P. Schultz.

***Pseudocheilinus hexataenia** (Bleeker)

Fowler and Ball, 1925, 6 specs. This record undoubtedly refers to either *Pseudocheilinus* sp. or *P. octotaenia*.

Pseudocheilinus octotaenia (Jenkins)

2 specs., 73 and 85 mm., 1951; 1 spec., 76 mm., Brock, 1948.

First dorsal rays not longer than those of the middle of the fin; three longitudinal rows of scales on cheek below eye; six to eight black longitudinal lines on sides, the lowermost well below the middle of the body; 14 rays in the pectoral fin counting the splint-like ray above.

Stethojulis axillaris (Quoy and Gaimard)

17 specs., 30–71 mm., 1951; 1 spec., 82 mm., Brock, 1948.

One or more black dots along the middle of the caudal peduncle.

Thalassoma ballieui (Vaillant and Sauvage)

Fowler and Ball, 1925, 1 spec. As *Julis verticalis* Smith and Swain, 1882, 1 spec.

Fowler and Ball's specimen has been reexamined. Though in poor condition, it does show the concentration of vertical markings on the scales on the caudal peduncle.

Thalassoma duperrey (Quoy and Gaimard)

16 specs., 55–162 mm., 1951; 1 spec., 146 mm., Brock, 1948. Halstead and Bunker, 1954, 1 spec. As *Julis clepsydralis* Smith and Swain, 1882, 1 spec.

A distinct light brown cross band through shoulder region in life, the fish becoming plain dark in preservative without marks except often for a dark mark on the upper edge of the pectoral base.

Thalassoma lutescens (Lay and Bennett)

5 specs., 53–116 mm., 1951. As *Thalassoma aneitense*, Fowler and Ball, 1925, 1 spec.

This species, of greenish yellow coloration in life, agrees well with Jordan and Evermann's plate (1905, pl. 41, as *T. aneitense*) except that each scale has an indistinct vertical stripe. However, there seems to be no way besides color by which to distinguish these specimens from *T. duperrey*, and it might prove difficult to refute the view that they simply represent a color variant of *T. duperrey* (similar to the yellow phase of *Epibulus insidiator*). The absence of canine teeth given by Jordan and Evermann (*op. cit.*) is valueless. Johnston specimens of *T. lutescens* have canine teeth exactly as in *T. duperrey*.

Thalassoma purpureum (Forskål)

Fowler and Ball, 1925, 1 spec.

This specimen has been reexamined. It has the broad band, branching below, extending

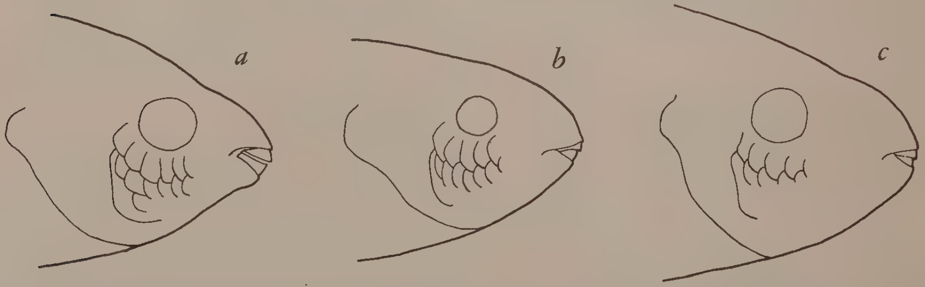

FIG. 2. Heads of species of *Scarus*. *a*, *Scarus dubius*, from a specimen 4¼ inches in total length with the mouth slightly open and the lips somewhat retracted; *b*, *Scarus sordidus*, from a 5¾-inch specimen; *c*, *Scarus perspicillatus*, from a 5½-inch specimen.

down and back from the eye typical of the species.

Thalassoma quinquevittata (Lay and Bennett)

10 specs., 48–110 mm., 1951; 1 spec., 62 mm., Brock, 1948.

Distance from tip of snout to origin of dorsal less than distance from tip of snout to origin of pelvics; a dark band around chin in adults; several dark marks along dorsal base in young.

SCARIDAE

Calotomus sandvicensis (Cuvier and Valenciennes)

7 specs., 90–235 mm., 1951.

The species of *Calotomus*, like those of *Scarus* (see below), are badly confused, and this must be considered a tentative identification.

Genus SCARUS

The present classification of the species of central Pacific parrot fishes is a mess. However, the group is in the process of being monographed (Schultz, ms.). In view of this the aims of the present account are quite limited. They comprise an attempt to separate what seem to be the three commonest species of the genus *Scarus* in Hawaiian waters (which happen to be the three species taken at Johnston) and to see to what extent the green and brown color phases of these species are correlated with sexual differentiation and maturity.

KEY TO THE SPECIES OF *Scarus* COLLECTED AT JOHNSTON ISLAND

1a. Lower (horizontal) limb of preopercular border relatively little developed (Fig. 2*b*, *c*), the length of its free edge (measured to the point at which the border runs vertically) less than the distance from its most anterior point to the midventral line; upper tooth plate never completely covered by the upper lip; pectoral rays usually 14 (not counting the small splint at the top); outline of the border of pelvic fins usually rounded; outer caudal rays never prolonged; canine teeth at the corners of the upper tooth plate, if present, low and knob like . . . **2**

1b. Lower limb of preopercular border relatively well developed (Fig. 2*a*), its length equal to or greater than the distance from its most anterior point to the midventral line; upper tooth plate, when retracted, completely covered by the upper lip; pectoral rays 13 (14 in one out of 14 specimens); pelvic outlines usually pointed between the 1st and 2nd soft rays; caudal truncate in specimens up to 5 inches in total length (Fig. 3*a*, *b*), lunate in larger specimens (Fig. 3*c*) and usually with the outer rays prolonged in fishes between 8.5 inches and the maximum size attained (which is about 12 inches); adults usually with 1 to 3 conspicuous, conical, pointed canines at either side of the upper tooth plate. Two complete scale rows on cheek with sometimes a third incomplete row below (Fig. 2*a*); head of moderate size, less than the greatest depth of body in specimens over 6 inches long . . . . **dubius**

2a. Lower of the two scale rows on cheek, if present, incomplete, consisting of 1 to 3 scales; head relatively smaller, its length considerably less than the greatest body depth; attains at least 2 feet in length . . . . **perspicillatus**

2b. Lower of the two scale rows on cheek about as long as the upper, consisting of 5 to 7 scales; head relatively large and bullet shaped, its length about equal to the greatest depth of body; apparently does not reach a length of over 1 foot . . . . **sordidus**

Scarus dubius (Bennett)

13 specs., 39–162 mm., 1951 (brown form). As *Scarus brunneus*, Halstead and Bunker, 1954, 1 spec.

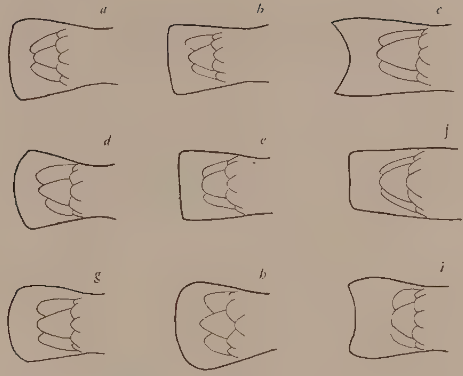

FIG. 3. Caudal fin outlines of *Scarus. a–c, Scarus dubius, a*, 2¾ inches in total length, *b*, 4¼ inches, *c*, 7¾ inches; *d–f, Scarus sordidus, d*, 3½ inches, *e*, 5¾ inches, *f*, 7 inches; *g–i, Scarus perspicillatus, g*, 2¾ inches, *h*, 5½ inches, *i*, 12¾ inches.

The rather extensive forward projection of the free preopercular border (Fig. 2*a*) is perhaps the most reliable way of distinguishing the species here tentatively identified as *S. dubius* from the other two species of *Scarus* dealt with here. The following distinguishing features, though helpful, appear to be less reliable. The pectoral rays are usually 13 instead of 14. When the jaws are retracted and the lips are in normal position, the upper lip extends down as a flap over the whole of the upper tooth plate; however, if the jaws are incompletely retracted (even though they may be partially closed as in Fig. 2*a*) or if the lips have been pushed back, the upper tooth plate may protrude. In the other two species the lips never cover the tooth plates except in very small specimens (less than 3 inches in total length). The two, more or less complete scale rows on the cheek will separate *S. dubius* from *S. perspicillatus* but not from *S. sordidus*. Certain features that change with growth are useful in separating *S. dubius* from the other two species if specimens of the same size are compared. Thus *S. dubius* develops a lunate caudal at a length of 7 inches in total length, whereas *S. perspicillatus* does not have a lunate caudal at sizes below 12 inches and *S. sordidus* apparently never does have a lunate caudal. Again, *S. dubius* at a length of perhaps 7 inches usually develops one or two outwardly projecting canines at each corner of the upper jaw, but the other two species apparently never develop these beyond the stage of small, rounded tubercles.

Among the Hawaiian species of *Scarus* for which accounts are given by Jordan and Evermann (1905) the brown form here called *S. dubius* appears to have been included three times: as *Callyodon brunneus* (p. 349), *C. dubius* (p. 350), and as *C. bennetti* (p. 352). These, except for *C. brunneus*, differ in certain details from the form at hand. The major differences judging from Jordan and Evermann's accounts, are as follows: *Callyodon dubius* is said to have 14 pectoral rays; the pectoral count of the present specimens is usually 13. *C. bennetti* is figured with a rounded caudal (but this may be due to the small size of the specimen), the lips are said not to cover the upper jaw, and there are white lines along the scale rows of the lower sides (I have yet to see such markings). Though it is quite possible that more than one species is represented in the above group, a reexamination of Jordan and Evermann's material would be necessary to determine this. Of the three names, *S. dubius* (Bennett) is the oldest. Bennett's original description (1828: 828; type locality Oahu) is very sketchy. However, Günther has redescribed the type, along with other specimens, in two places (1862: 229; 1909: 313). In both of these redescriptions Günther mentions the presence of two scales in a row below the other two cheek rows. The species here dealt with is the only unspotted, brown Hawaiian *Scarus* known to me in which this third row ever occurs.

Scarus dubius apparently does not reach a large size. The largest brown specimen from Johnston is about 8 inches in total length. The largest specimen mentioned in Jordan and Evermann's accounts of *Callyodon brunneus*, *dubius*, and *bennetti* is 9.5 inches.

Of the five individuals more than 6 inches long from Johnston two, 6.4 and 8 inches long, are mature or maturing females. The ovaries are elongate, paired organs without sharp edges and contain small elongate eggs. The three other specimens, 7 to 7.4 inches in total length, contain in the ovarian position and behind the liver, flat, sharp-edged organs. The extent to which these structures are developed in the three individuals varies greatly. At one extreme they are small and leaf like. At the other they are somewhat larger than the largest ovary in the females mentioned above, rather thick, and overlap the intestines at the sides, above, and behind. These large structures must, I think, be identified as ripe testes.

The brown *Scarus dubius*, like the other two species to be dealt with, seems to have a green counterpart. Before discussing this, it seems advisable to say something about green parrot fishes in general based on experience with the scarids in Hawaii and elsewhere. Young parrot fishes, up to about 2 inches in length, are frequently, perhaps always, a plain light green color. These gradually become brownish with growth and I have never seen a green scarid between 3 inches and about 7 inches long. Green parrot fishes (more than 7 inches long) invariably have adult characteristics. In all the three species dealt with here, the size of the green counterpart is comparable to or somewhat larger than the mature brown form. Thus the green counterparts of small brown forms, e.g., *S. dubius* and *S. sordidus*, are always relatively small while those of large brown forms, e.g., *S. ahula* (=*perspicillatus*), are always relatively large. I have never seen a female green scarid, though, as just noted, some brown specimens appear to be adult males. Finally, green parrot fishes seem to be relatively rare as compared with brown individuals, though the distinctiveness in the color markings of the green as contrasted with brown forms has led to the description of numerous green species.

The green counterpart of *S. dubius* is represented in the University of Hawaii collections by four specimens 170 to 190 mm. in total length that died in the Honolulu Aquarium and by one taken at Kailua, Kona, Hawaii. The aquarium specimens are so badly damaged that an exact correspondence in many morphological characters between them and the brown *S. dubius* could not be checked. They do agree in having two scale rows on the cheek, a relatively long horizontal limb to the free preopercular border, 13 pectoral rays, pointed ventrals, and a rather small head. In only two of the four could gonads be found. In these there were relatively small, elongate, sharp edged organs without eggs that must be considered testes.

The 12 inch Kailua specimen is in better condition and hence of greater interest. It is an unripe male; I can only find a testis on the left side. The description of the morphological characters given for the adult brown *S. dubius* fits this specimen completely. The mouth is closed and the upper lip projects forward as a flap over the whole upper tooth plate. The pectoral rays are 13 on each side and there are two complete rows of scales on the cheek. There is a single outwardly-projecting canine on each side of the upper jaw. The caudal is lunate and the outermost soft pelvic ray extends well beyond the others.

Jordan and Evermann (*op. cit.*) recognize six green species of *Scarus* from the Hawaiian islands: "*Callyodon*" *perspicillatus* (p. 347), *C. jenkinsi* (p. 353), *C. gilberti* (p. 354), *C. formosus* (p. 355), *C. lauia* (p. 355), and *C. bataviensis* (p. 356). Of these *Scarus perspicillatus* has the lower row of cheek scales incomplete, and Brock and Yamaguchi (1954: 154) have already demonstrated that it is the adult male of "*S. ahula.*" The color description and plate given by Jordan and Evermann for *Scarus lauia* is decidedly dissimilar to that of the specimen at hand and seems to represent an entirely different species. As for the remaining forms: *S. jenkinsi*, *S. gilberti*, *S. formosus*, and *S. bataviensis*, there is nothing in Jordan and Evermann to indicate that any or all of them are not the species represented by the Kailua specimen. I can see nothing to indicate that this in turn is not an old male of the brown form represented by *S. dubius*. Since *S. dubius* is the oldest name to be applied in either the brown or the green complex dealt with, it may be, at least provisionally, used for this species.

Scarus sordidus Forskål

78 specs., 57–222 mm., 1951 (75 brown, 3 green); 5 specs., 115–175 mm., Brock, 1948. Fowler and Ball, 1925, 2 specs.

This species does not seem to be among those described by Jordan and Evermann and the identification for it was kindly provided by Dr. L. P. Schultz of the U. S. National Museum. It has a characteristic bullet-shaped head and usually has the tooth plates protruding well beyond the lips. These tooth plates are of a dirty, greenish tinge in alcohol. The caudal of this species is rounded in small specimens but truncate in fishes 5.5 inches in total length and larger. It is the most elongate of the three species, and the eye is smaller than in the other two species at the same size. The anal rays are somewhat shorter than in *S. perspicillatus* (longest anal ray contained 1.85–2.34 in anal base of *S. sordidus*, 1.44–1.98 in *S. perspicillatus*). This form often has a white band on the caudal peduncle and there is frequently a black spot in the middle of the band.

It seems to be the commonest scarid at Johnston and not at all infrequent around Oahu. The largest specimen of this brown form taken is about 9 inches long. Most of the specimens more than 5 inches long are mature females with eggs. The ovaries are similar to those of *S. dubius* and are paired in the single specimen checked. Again certain specimens contain the asymetrical, liver-like structure found in the brown form of *S. dubius*. Of a dozen brown specimens checked, one 4.5 inches long was an immature. The rest are larger, the largest being 8.3 inches in total length. Of these, 8 are mature females, and 3 have a large, flattish liver-like organ in the ovarian position. The size of this flattish organ, when present is, in 2 out of the 3 specimens, larger than the largest ovary. This seems peculiar if it is a testis, but repeated attempts to find eggs in it have failed. The facts that the liver is also present in these specimens, that there are no other gonad-like structures along with it, and that it contains no eggs seems to leave little alternative to identifying the structure as a testis despite its size.

Three green specimens, 10.2 to 10.5 inches in total length, were taken with the brown form from Johnston described above. These all duplicate the brown form of *S. sordidus* in morphological characters, e.g., the long head with greatly protruding, greenish tooth plates, the two complete scale rows on the cheek, rounded pelvics, etc. Though the outer caudal rays extend somewhat beyond the inner ones they are not produced as in the green form of *S. dubius*. There are from 0 to 3 small knobs at the sides of the upper jaw; these do not project outward to nearly the extent that they do in adult *S. dubius*. In all of these there is a flat organ on the right side, but in one of the three it does not seem to occur on the left. In this one the organ on the right side is quite small, in the other two of moderate size, considerably smaller than the same organ at its maximum development in the smaller brown form. I think two of the three green specimens may be considered ripe or ripening males and the third an unripe male. In color, these specimens, though faded, differ considerably from the green form of *S. dubius*. The pelvic and caudal coloration is quite plain and that on the head seems to have consisted of broad, indefinite dark bars around the mouth and behind the eye.

Scarus perspicillatus (Steindachner)

5 specs., 72–290 mm., 1951 (4 brown, 1 green). Smith and Swain, 1882, 1 spec.; Halstead and Bunker, 1954, 12 specs. As *Callyodon perspicillatus* Fowler and Ball, 1925, 4

specs. As *Callyodon ahula* Fowler and Ball, 1925, 2 specs.

Since Brock and Yamaguchi have already demonstrated (1954) that the green *S. perspicillatus* is the adult male of the brown *S. ahula*, and since my material adds little to this information, the account of this species may be cut short. Only five specimens of this species were taken at Johnston, four brown and one green. The green specimen, 14 inches in total length, is a ripe male with very large, paired testes. Of the brown form, specimens 4.5 to 9.5 inches in total length are immatures; the other, 14 inches long, is a ripe or ripening female. The large female differs from the ripe male (and from brown specimens of a similar size from Hawaii) in the considerably greater depth of body, but I can see no other characters on which to separate them.

Additional species of *Scarus* recorded from Johnston are:

***Scarus cyanogrammus** (Jordan and Seale)
Halstead and Bunker, 1954, 1 spec.

***Scarus duperrey** (Quoy and Gaimard)
Halstead and Bunker, 1954, 1 spec.

***Scarus erythrodon** Cuvier and Valenciennes
As *Callyodon erythrodon*, Fowler and Ball, 1925, 4 specs.

***Scarus forsteri** Valenciennes
Halstead and Bunker, 1954, 1 spec.

CHAETODONTIDAE

Centropyge flammeus Woods and Schultz
4 specs., 70–81 mm., 1951. Woods and Schultz, in Schultz, *et al.*, 1953, 6 specs. As *Holacanthus loriculus*, Fowler and Ball, 1925, 1 spec.

***Centropyge nigriocellus** Woods and Schultz
Woods and Schultz, in Schultz, *et al.*, 1953, 1 spec.

Chaetodon auriga Forskål
14 specs., 112–145 mm., 1951; 1 spec., 117 mm., Schaefer, 1948. Halstead and Bunker, 1954, 7 specs. As *Chaetodon setifer*, Smith and Swain, 1882, 1 spec. and Fowler and Ball, 1925, 5 specs.

Chaetodon citrinellus Cuvier
5 specs., 92–100 mm., 1951. Halstead and Bunker, 1954, 1 spec.

Chaetodon ephippium Cuvier
2 specs., 124 and 158 mm., 1951. Fowler and Ball, 1925, 1 spec.; Halstead and Bunker, 1954, 2 specs.

Chaetodon multicinctus (Garrett)
3 specs., 86–89 mm., 1951. As *Chaetodon punctatofasciatus*, Fowler and Ball, 1925, 3 specs. and Halstead and Bunker, 1954, 2 specs.

This species is dealt with briefly in section 2.

Chaetodon ornatissimus Solander
4 specs., 110–147 mm., 1951. Fowler and Ball, 1925, 3 specs.; Halstead and Bunker, 1954, 4 specs.

Chaetodon quadrimaculatus Gray
2 specs., 108 and 108 mm., 1951. Fowler and Ball, 1925, 3 specs.

Chaetodon trifasciatus Mungo Park
Fowler and Ball, 1925, 5 specs. Determination checked.

Chaetodon unimaculatus Bloch
3 specs., 82–88 mm., 1951; 1 spec., 41 mm., Brock, 1948. Fowler and Ball, 1925, 6 specs.

***Megaprotodon strigangulus** (Gmelin)
Halstead and Bunker, 1954, 1 spec.

ZANCLIDAE

Zanclus cornutus Cuvier
1 spec., 98 mm., 1951. Halstead and Bunker, 1954, 1 spec. As *Zanclus canescens*, Fowler and Ball, 1925, 2 specs.

ACANTHURIDAE

Acanthurus achilles Shaw
18 specs., 114–210 mm., 1951. Halstead

and Bunker, 1954, 4 specs. As *Hepatus achilles*, Fowler and Ball, 1925, 3 specs.

Acanthurus elongatus (Lacepède)

54 specs., 80–126 mm., 1951. Halstead and Bunker, 1954, 13 specs. As *Hepatus lineolatus*, Fowler and Ball, 1925, 5 specs.

A small dark spot at the base of the last dorsal and anal rays.

Acanthurus olivaceus Schneider

1 spec., 200 mm., 1951. Halstead and Bunker, 1954, 6 specs. As *Hepatus olivaceus*, Fowler and Ball, 1925, 1 spec.

Fowler and Ball record 3 specimens of *Hepatus nigricans* from Johnston; one of these is in the Bishop Museum and is *Acanthurus olivaceus*.

Acanthurus sandvicensis Streets

21 specs., 63–127 mm., 1951. As *Acanthurus triostegus*, Smith and Swain, 1882, 2 specs. and Halstead and Bunker, 1954, 5 specs.; as *Hepatus sandvicensis*, Fowler and Ball, 1925, 7 specs.

This species will be treated in section 2.

***Ctenochaetus striatus** (Quoy and Gaimard)

Halstead and Bunker, 1954, 7 specs.

Ctenochaetus strigosus (Bennett)

11 specs., 72–106 mm., 1951; 1 spec., 80 mm., Brock, 1948. Fowler and Ball, 1925, 1 spec.

These specimens are included in Randall's report on the genus which is in press.

Naso lituratus (Schneider)

5 specs., 152–210 mm., 1951. Halstead and Bunker, 1954, 7 specs. As *Naseus lituratus*, Smith and Swain, 1882, 2 specs.; as *Acanthurus lituratus*, Fowler and Ball, 1925, 4 specs.

Zebrasoma flavescens (Bennett)

1 spec., 54 mm., 1951. Fowler and Ball, 1925, 3 specs.; Halstead and Bunker, 1954, 1 spec.

Plain yellow in color.

ELEOTRIDAE

Eviota viridis (Waite)

Fowler and Ball, 1925, 3 specs.

These specimens have been reexamined, but are in too poor condition to provide a definite identification.

GOBIIDAE

***Bathygobius fuscus** Rüppell

Fowler and Ball, 1925, 4 specs.

There seems no reason to doubt the original determination.

Gnatholepis anjerensis (Bleeker)

5 specs., 19–34 mm., 1951.

Tongue strongly bilobed; anal with 11 soft rays in all 5 specimens.

Zonogobius farcimen (Jordan and Evermann)

5 specs., 16–22 mm., 1951.

These specimens agree well with the description and figure of this species by Jordan and Evermann (1905).

BLENNIIDAE

Cirripectus variolosus (Valenciennes)

52 specs., 24–63 mm., 1951; 2 specs., 55 and 59 mm., Brock, 1948. As *Rupiscartes variolosus*, Fowler and Ball, 1925, 22 specs.

Body plain; nuchal cirri totaling 36 in one specimen; first dorsal rays elongate.

Exallias brevis (Kner)

1 spec., 46 mm., Brock, 1948.

A broad fleshy flap on either side of the chin; scattered reddish spots on the head, body, and fins.

Salarias gibbifrons (Quoy and Gaimard)

17 specs., 23–73 mm., 1951. As *Rupiscartes gibbifrons*, Fowler and Ball, 1925, 1 spec.

Long, simple, slender cirri over eye; middle of eye about over front of upper jaw; a spot between the first two dorsal spines.

BROTULIDAE

Brotula townsendi Fowler

1 spec., 127 mm., 1951.

This specimen has been reported on previously (Gosline, 1953).

MUGILIDAE

Neomyxus chaptalii (Eydoux and Souleyet)
1 spec., 286 mm., 1951. Fowler and Ball, 1925, 5 specs.

Forty-four scales in a longitudinal series.

SPHYRAENIDAE

***Sphyraena japonica** (Cuvier)
Fowler and Ball, 1925, 3 specs.

POLYNEMIDAE

***Polydactylus sexfilis** (Cuvier and Valenciennes)
As *Polynemus kuru*, Smith and Swain, 1882, 1 spec.

SCORPAENIDAE

Scorpaenids seem to be rare around Johnston, and the only two species taken are the two that are perhaps commonest around Hawaii. They are not difficult to separate but they have been badly confused. Nomenclatorially the difficulty starts at the generic level. Jordan and Evermann (1905) have placed the two in *Sebastapistes*. Schultz (1943), for reasons which are not clear, divides the members of *Sebastapistes* between *Scorpaenopsis* and *Scorpaena*. Matsubara (1943), who will be followed here, places all of *Sebastapistes* back under *Scorpaena*.

At the specific level a nomenclatorial problem also arises. The oldest name for any Hawaiian species is *Scorpaena asperella* Bennett (1828). The description of this species, based on a single specimen 2 inches long, gives almost no morphological characters of any value, and the coloration does not agree very well with anything subsequently found in the Hawaiian Islands. The type, according to Günther (1873: 80), has been lost. The name *Scorpaena asperella* has been applied in various ways. Günther (1860: 107) considered the species unrecognizable. Jordan and Evermann (1905) thought that the description applied to some Hawaiian species that they did not have. This seems rather unlikely, for of the 11 Hawaiian species described by Bennett 9 of the names have subsequently been identified among the most common of small inshore fishes and the other 2 have never been identified very satisfactorily with anything. One suspects that the difficulty with these 2 lies not in the rarity of the species described but in the nature of Bennett's descriptions. In 1943 Schultz (p. 172) applied the name to a species from Samoa.

I have repeatedly compared Bennett's description with small scorpaenids from Hawaii and can only conclude that it checks about as well (or as badly) with one as with another. Under the circumstances it seems best to follow Günther's usage in considering the name unrecognizable.

The following tabulation of characteristics will serve to distinguish the two species of *Scorpaena* collected at Johnston:

Eight spines on the top of the head above and behind the orbital rim, the front four in a transverse row; pectoral base without scaly sheath; cheek and opercle naked; pectoral with 4 branched rays; suborbital with a single blunt, backwardly projecting knob; no distinct, small dark spots; a black blotch usually present on the posterior part of the spinous dorsal in specimens more than 3 inches long; last dorsal ray attached for most of its length to the caudal peduncle by means of a membrane.................................. **S. ballieui**

Six spines on the top of the head above and behind the orbital rim; pectoral with a scaly sheath at base that extends well out onto the pectoral fin; cheek and opercle scaled; pectoral with 5 branched rays; suborbital with two divergent, backwardly projecting points; small, distinct dark spots on and below the base of the dorsal fin, on the head, and in the pectoral axil; no black blotch on the posterior part of the spinous dorsal; last dorsal ray attached to the caudal peduncle for less than half its length.......................................**S. coniorta**

Five species of *Sebastapistes* from Hawaii are recognized by Jordan and Evermann (1905: 455–460), and a sixth is described from deeper water by Gilbert (1905: 627). Of these *S. asperella*, as noted above, must apparently be considered unidentifiable. Of the others, *S. coniorta* seems to apply to the scaled-cheek species. Judging from Jordan and Evermann's descriptions, *S. balieui*, *S. corallicola*, and probably *S. galactacma* belong with the naked-cheeked species. *S. coloratus* appears to represent a third species.

At present it seems best to designate the two Johnston species as *Scorpaena ballieui* Sauvage and *S. coniorta* (Jenkins). Other related species have been described from elsewhere in the tropical Indo-Pacific, but in the absence of comparative material it is impossible to determine which of these are the same as the two Johnston species and which are different.

Scorpaena ballieui Sauvage

1 spec., 23 mm., 1951.

Scorpaena coniorta (Jenkins)

1 spec., 51 mm., 1951.

BOTHIDAE

Bothus mancus (Broussonet)

1 spec., 160 mm., 1951. Halstead and Bunker, 1954, 2 specs. As *Platophrys mancus*, Smith and Swain, 1882, 1 spec. and Fowler and Ball, 1925, 3 specs.

Dorsal 96; anal 78.

ECHENEIDAE

Remora remora (Linnaeus)

1 spec., 67 mm. from shark taken outside reef.

Pelvic fins with their inner rays attached to the abdomen for most of their length; laminae 17; lower jaw greatly exceeding upper in length.

BALISTIDAE

Melichthys buniva (Lacepède)

9 specs., 155–185 mm., 1951. Fowler and Ball, 1925, 3 specs. As *Balistes buniva*, Smith and Swain, 1882, 3 specs.

Dorsal and anal black with a narrow blue line at base. A very common species, which seemed to be thriving on the garbage periodically dumped into the lagoon at the time we were there.

*__Melichthys ringens__ (Osbeck)

Halstead and Bunker, 1954, 11 specs.

Melichthys vidua (Solander)

1 spec., 150 mm., 1951. Halstead and Bunker, 1954, 2 specs. As *Balistes vidua*, Fowler and Ball, 1925, 2 specs.

Dorsal and anal light except for the narrow dark borders. Fraser-Brunner's placement (1935: 662) of this species in the genus *Melichthys* seems questionable.

Rhinecanthus aculeatus (Linnaeus)

Halstead and Bunker, 1954, 3 specs. As *Balistes aculeatus*, Smith and Swain, 1882, 2 specs. and Fowler and Ball, 1925, 1 spec. (this record checked).

Three longitudinal rows of black spinelets on the caudal peduncle.

MONACANTHIDAE

*__Amanses carolae__ (Jordan and McGregor)

Halstead and Bunker, 1954, 2 specs.

Amanses sandwichiensis (Quoy and Gaimard)

3 specs., 140–270 mm., 1951. Halstead and Bunker, 1954, 1 spec. As *Monacanthus sandwichiensis*, Fowler and Ball, 1925, 1 spec.

The 140 mm. specimen has no spines on the caudal peduncle; the two larger (190 and 270 mm.) have 4 forwardly projecting spines in two rows on each side.

Pervagor melanocephalus (Bleeker)

3 specs., 82–106 mm., 1951. As *Monacanthus melanocephalus*, Fowler and Ball, 1925, 4 specs.

Dorsal rays 32 in one specimen.

OSTRACIONTIDAE

***Kentrocarpus hexagonus** (Thunberg)
Halstead and Bunker, 1954, 1 spec.

***Ostracion cubicus** Linnaeus
Halstead and Bunker, 1954, 1 spec.

Ostracion lentiginosum Schneider
15 specs., 76–126 mm., 1951. Fowler and Ball, 1925, 3 specs. As *Ostracion punctatum*, Smith and Swain, 1882, 1 spec.

***Ostracion meleagris** Shaw
Halstead and Bunker, 1954, 9 specs.

Ostracion solorensis Bleeker
Fowler and Ball, 1925, 1 spec.

This specimen has the upper sides with alternating brown and white stripes, the brown ones continuous but the white ones broken up into segments. Below the banded area the body is abruptly light. A very slight dorsal ridge just ahead of dorsal fin; ventrolateral ridges expanded into laminae. Carapace closed over behind the dorsal and anal fins to form two horizontal laminae. Supraorbital ridges somewhat raised and rough. No spines anywhere.

TETRAODONTIDAE

Arothron meleagris (Lacepède)
2 specs., 140 and 160 mm., 1951. Halstead and Bunker, 1954, 1 spec. As *Tetraodon meleagris*, Smith and Swain, 1882, 3 specs., Fowler and Ball, 1925, 4 specs.

Head, body, and fins with small light spots on a dark ground. Outer portions of fins, except caudal, light.

CANTHIGASTERIDAE

Canthigaster jactator (Jenkins)
3 specs., 40–64 mm., 1951; 1 spec., 52 mm., Brock, 1948. Halstead and Bunker, 1954, 1 spec.

Round white spots on a dark ground.

DIODONTIDAE

***Diodon hystrix** Linnaeus
Smith and Swain, 1882, 1 spec.

SECTION 2. THE NATURE AND RELATIONSHIPS OF THE JOHNSTON ISLAND FISH FAUNA

Johnston Island is one of the more isolated of Pacific atolls. It is separated by some 450 miles of deep water from the nearest reef area, French Frigate Shoals in the Hawaiian chain to the north (see Fig. 1). To the south and east the nearest shoal water (Kingman Reef in the Line Islands) is about 700 miles away, whereas the closest land to the west is in the Marshalls perhaps 1300 miles distant.

The position of Johnston Island poses two principal questions for the zoogeographer: (1) to what extent does its isolation give rise to endemism, and (2) to what extent has Johnston acted as a stepping stone or filter bridge between the Hawaiian biota and that of the Line Islands to the south. An attempt to answer these two questions constitutes the present section of this paper.

Before proceeding it seems well to define certain terms that will be used here. "Central Pacific" will be employed in a zoogeographic sense to refer to a faunal area whose limits are unknown but which includes the Line, Phoenix, Gilbert, and Marshall islands but *not* Johnston and the Hawaiian chain. "Hawaiian" used zoogeographically will refer to the inshore marine fauna of the Hawaiian chain together with that of Johnston. "Hawaii" used geographically generally refers to the Hawaiian chain of islands, though the fact that the largest island in this chain is also called Hawaii is admittedly confusing.

The question of endemism among Johnston fishes is easily dealt with and dismissed. Only two species of Johnston fishes have not been taken elsewhere—*Centropyge nigriocellus* and *C. flammeus*. Neither of these is abundant at Johnston (the former is known only from one specimen), and it may well be that they merely remain uncollected elsewhere. In a few other fishes the Johnston specimens seem somewhat aberrant but probably do not deserve recognition as separate species. The principal significance of this low degree of endemism at Johnston lies in the demonstration that for Pacific island fishes 450 miles of open water without strong current systems has not resulted in much differentiation.

The problem of evaluating Johnston as a filter bridge is far more complex. The present attack on it is divided into two facets. The first approaches the problem in terms of the relative strengths of the various components of the Johnston shallow-water fish fauna. The objective here is to obtain a general picture of the relationships of the fish fauna of Johnston Island. The second deals in greater detail with certain Johnston fishes that are represented by different geographic forms south of the island than occur to the north. Its objective is to trace, in so far as possible, individual migration routes.

Components of the Johnston Fish Fauna

For purposes of the faunal analysis that follows, certain families of fishes have been excluded for one reason or another. First, those fishes that are pelagic or semipelagic as adults are omitted. For these, Johnston may have no significance whatever as a way point, and to include them would only obscure the data. Groups excluded from consideration for this reason are the sharks and rays, the needle fishes, half-beaks, flying fishes, carangids, barracudas, tunas, remoras, and all fishes taken from over 100 feet of water. Second, the parrot fishes and scorpaenids have also been excluded, but for the reason that at the present time they are so confused taxonomically as to make species records worthless zoogeographically. Finally, the species recorded from Johnston by Halstead and Bunker (1954) only will not be considered as I have not been able to check their records. Fowler and Ball's (1925) species have, on the other hand, been included because, as already mentioned, material upon which their more questionable identifications were based have been reexamined. Following is the reduced list of Johnston species, upon which the following analysis is based.

SPECIES CONSIDERED IN THE ANALYSIS OF THE JOHNSTON FISH FAUNA

Central Pacific Species Reaching Johnston but Not Hawaii (Group B of Fig. 4)

Leptenchelys labialis
Muraenichthys gymnotus
Muraenichthys schultzei
Brachysomophis sauropsis
Myrichthys bleekeri
Echidna leucotaenia
Uropterygius polyspilus
Kuhlia marginata
Parupeneus barberinus
Abudefduf phoenixensis
Epibulus insidiator
Thalassoma quinquevittata
Pervagor melanocephalus
Ostracion solorensis

Species Endemic to Johnston (Group G of Fig. 4)

Centropyge flammeus
Centropyge nigriocellus

Hawaiian Species Reaching South to Johnston but Not Beyond (Group E of Fig. 4)

Muraenichthys cookei
Gymnothorax eurostus
Uropterygius dentatus
Apogon menesemus
Apogon waikiki
Parupeneus multifasciatus
Cirrhitus alternatus
Chromis leucurus
Chromis vanderbilti
Dascyllus albisella
Halichoeres ornatissimus
Thalassoma ballieui
Thalassoma duperrey
Chaetodon multicinctus
Acanthurus sandvicensis
Zonogobius farcimen

Johnston Species Found Both in Hawaii and in the Central Pacific (Group C of Fig. 4)

Saurida gracilis
Synodus binotatus
Conger noordziekii
Leiuranus semicinctus
Myrichthys maculosus
Schultzidia johnstonensis
Moringua macrochir
Anarchias allardicei
Anarchias cantonensis
Anarchias leucurus
Echidna polyzona
Echidna zebra

Gymnothorax gracilicauda
Gymnothorax meleagris
Gymnothorax moluccensis
Gymnothorax pictus
Gymnothorax undulatus
Rabula fuscomaculata
Uropterygius fuscoguttatus
Uropterygius tigrinus
Aulostomus chinensis
Fistularia petimba
Holocentrus tiere
Holocentrus microstomus
Holocentrus lacteoguttatus
Holocentrus sammara
Holocentrus spinifer
Holotrachys lima
Myripristis argyromus
Apogon erythrinus
Apogon snyderi
Pseudamiops gracilicauda
Pseudogramma polyacanthus
Priacanthus cruentatus
Kyphosus vaigiensis
Mulloidichthys auriflamma
Mulloidichthys samoensis
Parupeneus bifasciatus
Parupeneus chryserydros
Parupeneus pleurostigma
Paracirrhites bimacula
Abudefduf imparipennis
Abudefduf sordidus
Plectroglyphidodon johnstonianus
Bodianus bilunulatus
Cheilinus diagrammus
Cheilinus rhodochrous
Gomphosus tricolor
Gomphosus varius
Novaculichthys taeniourus
Pseudocheilinus sp.
Pseudocheilinus octotaenia
Stethojulis axillaris
Thalassoma lutescens
Thalassoma purpureum
Chaetodon auriga
Chaetodon citrinellus
Chaetodon ephippium
Chaetodon ornatissimus
Chaetodon quadrimaculatus
Chaetodon trifasciatus
Chaetodon unimaculatus
Zanclus cornutus
Acanthurus achilles
Acanthurus elongatus
Acanthurus olivaceus
Ctenochaetus strigosus
Naso lituratus
Zebrasoma flavescens
Bathygobius fuscus
Gnatholepis anjerensis
Exallias brevis
Cirripectus variolosus
Salarias gibbifrons
Brotula townsendi
Neomyxus chaptalii
Polydactylus sexfilis
Bothus mancus
Rhinecanthus aculeatus
Melichthys buniva
Melichthys vidua
Amanses sandwichiensis
Ostracion lentiginosum
Arothron meleagris
Canthigaster jactator
Diodon hystrix

For purposes of assessing the importance of Johnston as a filter bridge for species coming up from the south the following groupings have been made (see Fig. 4): (A) those fishes that never reached Johnston, (B) those that got to Johnston but no farther, (C) those that apparently passed through Johnston on the way from the Line Islands to Hawaii or vice versa, and (D) those that apparently by-passed Johnston. Similarly, the Hawaiian species may be divided into (F) those that never reached Johnston, (E) reached Johnston and stopped, (C) passed through Johnston, and (D) by-passed Johnston.

The stringency of the Johnstonian filtering effect on northbound and on southbound fishes will be shown by the relative strengths of each of the above categories (except D). An attempt to quantify each of these relative to one another is therefore made in Figure 4 by means of the widths of the columns. Widths of columns B, C, E, and G are based directly on the relative number of Johnston species in each of these categories in the list Column D is given no width, because it is impossible to know how much of column D is represented but as yet uncollected at Johnston. Widths for A and F were estimated in a very simple and admittedly imperfect fashion, and indicate only rough magnitudes. Two shallow-water poison stations run at Palmyra, the nearest island to the south of Johnston, by Mr. J. E. King, *et al.*, in approximately the same way as those made at Johnston yielded (among the same fish groups used here) 62 species of which 29 are not known from Johnston or Hawaii. Thus, the number of species in these two collections (and presumably in the Palmyra inshore fish fauna as a whole) that does not get north is calculated as 29/33 of the number that does. Consequently column A is assigned a width slightly less than the combined widths of B and C, which had been calculated previously. Similarly, the width of F is based on an inshore Oahu rotenone station from which 69 species in the same groups were collected. Of these, 17 do not get as far south as Johnston. Hence F is assigned a width about one third (actually 17/52) of the combined widths of C and E.

The fact that there are 16 Hawaiian species found at Johnston but not, apparently, farther south and 14 Central Pacific species that get to Johnston but not farther north indicates that at the present time Johnston is acting as a filter bridge for fishes passing in both directions. The nature of the filtering effect on northbound and on southbound species must now be considered.

Starting at the south, a very large component of the two poison stations run at Palmyra (29 of 52 species) is not known in Johnston or Hawaii. Two very striking members of this component are the genera *Lutjanus* and (except for a single species) *Epinephelus*. One immediately wonders if these fishes never got to the northern islands or whether they got there but have been unable to survive there because of unsuitable ecological conditions. If the latter were correct, one would suspect the colder water temperatures in the north to be either the direct or indirect cause of the unsuitability. There are certain indications that distance rather than water temperature has been the primary cause in preventing Central Pacific species from reaching Johnston and Hawaii. One of these is provided by the fishes of Japan. The southern Japanese Islands are separated by no such deep-water distances from tropical Pacific islands as Johnston is from Palmyra, but surface water temperatures in southern Japan are at least as cold as those of the Hawaiian Islands (Sverdrup, Johnson, and Fleming, 1946: charts II and III, and fig. 32B). Nevertheless, 15 species of *Epinephelus* (Tanaka, 1931: 26) and 14 species of *Lutjanus* (Kamohara, 1954: 114) are recorded from Japan. This suggests that the Hawaiian water temperatures would not be unsuitable for at least some species of *Lutjanus* and *Epinephelus*. An attempt to find an area separated from the tropical Pacific by a deep-water barrier as great as that isolating the Hawaiian Islands and Johnston leads to an examination of the tropical American data. Snodgrass and Heller (1905: 338) list some 13 species of inshore tropical Pacific species as occurring in the islands of the west coast of the Americas. Of these, none belong to the genera *Lutjanus* or *Epinephelus* or to any of the other species that are not represented at Johnston and Hawaii. To state this last matter positively, all 13 have representatives in the Hawaiian Islands today. These two straws in the wind indicate that the great diminution in species between Palmyra and Johnston is caused primarily by (deep-water) distance rather than by temperature. Such a distance effect could, of course, be either primary or secondary. If primary, the fishes themselves have been unable to get to Johnston; if secondary, the fishes may have been able to get there but the organisms they depend upon for a livelihood have not. Though there is no way of determining which of these two possibilities has been realized, it seems improbable that such unspecialized carnivorous genera as *Lutjanus* and *Epinephelus* would have found the food supply inadequate, had they arrived there.

Of those tropical fishes that have reached Johnston, the great majority seem to have passed on through to Hawaii. There are, however, 14 species that are not known north of Johnston. Some of these, e.g., *Epibulus insidiator*, are quite striking members of the tropical Pacific fauna, and it seems improbable that they should go unrecorded in the Hawaiian fauna if they exist there. One suspects that the reason they have not crossed the minor water gap between Johnston and

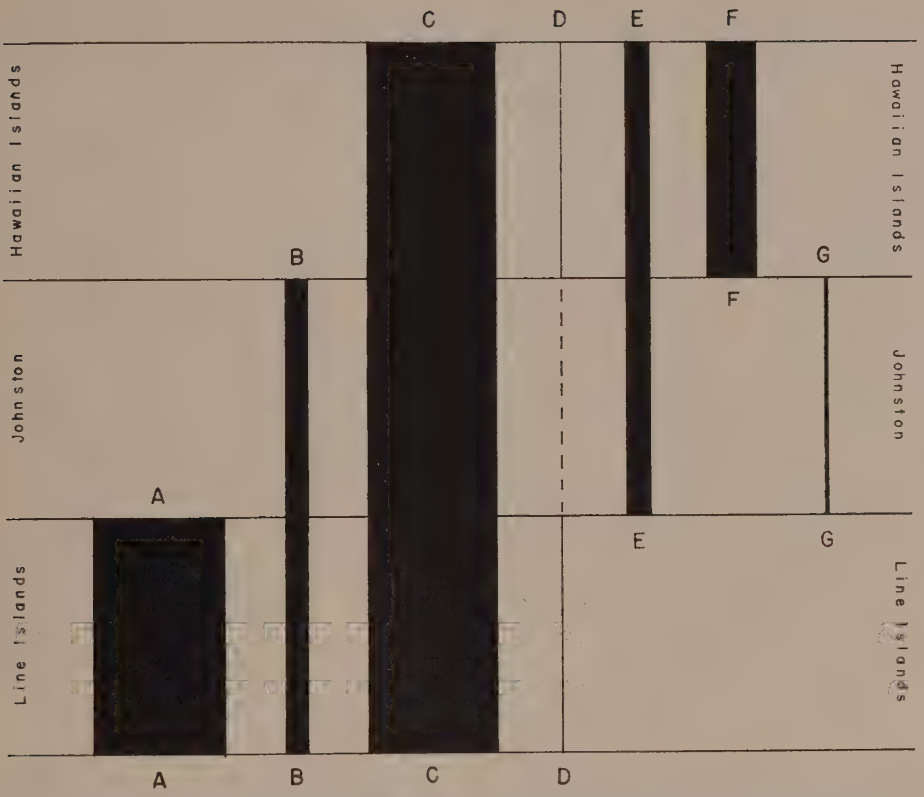

FIG. 4. Diagram of the zoogeographic components making up the inshore fish fauna of Johnston Island and the island chains nearest to Johnston. A, that portion of the Line Island fauna that does not reach Johnston or the Hawaiian Islands; B, that portion of the Line Island fauna that reaches to Johnston but not to the Hawaiian Islands; C, the component that is held in common by the Line Islands, Johnston, and the Hawaiian Islands; D, the component that is common to the Line and Hawaiian Islands but has not, up to now, been recorded from Johnston; E, that portion of the Hawaiian fauna that has reached Johnston but not farther south; F, the portion of the Hawaiian fauna that is restricted to the Hawaiian chain; and G, the component restricted to Johnston Island. Widths of the bars, except D, represent the relative strengths of the various components; for the way in which these widths were calculated, see text.

Hawaii after hurdling the major one between Palmyra and Johnston is that the ecological conditions in Hawaii are not suitable to them. This is of course merely a guess, but it may be noted that the Johnston coral reefs, made up as they are to a considerable extent of *Acropora*, would seem to form a quite different environment from the Hawaiian reefs, where *Acropora*, amongst other elements, is lacking. To bulwark this point further it may be noted that certain rather prominent components of the tropical Pacific fauna that do reach Hawaii are rare there and apparently do not find the environment particularly suitable. In this category belong such species as *Gymnothorax pictus*, *Holocentrus microstomus*, *Thalassoma lutescens*, *Chaetodon citrinellus*, *Chaetodon ephippium*, *Pomacanthus imperator*, and *Acanthurus aliala*.

Summing up for the "northbound" fishes

it appears that: (1) close to a half of the Line Island inshore fish fauna does not occur in Johnston or Hawaii and that the principal reason for this is the great area of deep water between the northernmost Line Island reef and Johnston; (2) the majority of tropical Pacific fishes that have reached Johnston also occur in Hawaii; (3) the relatively few species of tropical Pacific fishes that are known from Johnston but not Hawaii may have reached but have not survived in the latter islands because of differences in ecological conditions between Johnston and the Hawaiian chain.

What may be termed the southbound fishes are now up for discussion. In the first place it must be noted that there is a very much smaller proportion of the Hawaiian inshore fishes restricted to the Hawaiian Islands (F of Fig. 4) than of tropical Pacific fishes that do not get north from the Line Islands (A of Fig. 4). Indeed, it is quite certain that there is a considerably smaller number of Hawaiian "endemics" with the potentialities for moving south than of tropical Pacific fishes that might move north. Of the former group a rather high percentage (though a low number of species) have reached Johnston. It is for this reason that Johnston is to be considered primarily as an outlier of the Hawaiian faunal region rather than as a part of the tropical Central Pacific fauna. The example drawn from the Palmyra and Hawaiian poison stations will bring out this point. In the Hawaiian rotenone station of 69 species, only 17 are restricted to Hawaii, but another 4 are restricted to Hawaii and Johnston. In the Palmyra poison stations of 62 species, 29 are not known north of Palmyra but only 1 is known from Palmyra and Johnston but not Hawaii. On the basis of these figures (fishes found both in Hawaii and Palmyra being excluded) the Johnston inshore fauna is 4/17 Hawaiian and 1/29 tropical Pacific. To what extent other Hawaiian endemics will turn up at Johnston remains to be seen.

Finally, it is necessary to say something of those fishes found today in Hawaii, Johnston, and the tropical Pacific (C of Fig. 4). First, it seems certain that as more attention is given to the fishes in this category more of them will prove to show differentiation between the Hawaiian and Line Islands. Meanwhile there is no sure way of telling whether this group has moved north or south via Johnston. However, certain points regarding the hypothesis of Johnston as the original port of entry for the Hawaiian fauna may be mentioned. On the one hand, it is certain that the Hawaiian inshore fish fauna was ultimately derived from that of the tropical Pacific. Further, there is no island that could or does at the present time provide a better stepping stone between the Hawaiian chain and the tropical Pacific fauna. Finally it has been indicated above that Johnston does at the present time serve as a terminal point for at least some northward movement. On the other hand, the age of Johnston is unknown, and it may be that Johnston is younger than the Hawaiian fish fauna as we know it at present. If this were so, it would be far easier to explain why the following Hawaiian representatives of tropical Pacific forms rather than the latter forms themselves are present at Johnston: *Muraenichthys cookei*, *Gymnothorax eurostus*, *Cirrhitus alternatus*, *Chromis leucurus*, *Chaetodon multicinctus*, and *Acanthurus sandvicensis*. Because of these features it seems best not to make categorical statements as to whether (or how much of) the Hawaiian fish fauna did or did not originally enter via Johnston. It can, however, be stated that a more plausible port of entry has yet to be found.

Analysis of Individual Species

The individual species investigated here are Johnston fishes represented by different geographic variants in the Central Pacific and in the Hawaiian chain. They do not include all fishes in this category but only those for which sufficient information is available to be worth discussing. The following species complexes will be dealt with (in each pair the Hawaiian form is mentioned first): *Murae-*

nichthys cookei–laticaudata, *Gymnothorax eurostus–buroensis*, *Kuhlia sandvicensis–marginata*, *Cirrhitus alternatus–pinnulatus*, *Chaetodon multicinctus–punctato-fasciatus*, and *Acanthurus sandvicensis–triostegus*. A uniform treatment for all six species would be desirable in order to enable comparison of all six area by area. Unfortunately the availability of specimens makes this impossible.

Before these species are dealt with, it seems advisable to provide certain background information. The Johnston collections were originally made to check whether the endemic Hawaiian fishes were really species or merely subspecies. It was felt that intergradation between the Hawaiian endemics and their Central Pacific counterparts would occur at Johnston if anywhere. It does not occur there (or elsewhere) among any of the fishes here investigated, and on the basis of absence of intergradation (the term is here used in contrast with introgression) the Hawaiian endemics must be considered full species. But would the Hawaiian endemics interbreed with their Central Pacific counterparts if both were present? There is no way of determining this at Johnston, because the two never occur together there (or elsewhere). When a Central Pacific fish is represented by a variant in Hawaii, either the Central Pacific form (e.g., *Kuhlia marginata*) or the Hawaiian form (e.g., *Muraenichthys cookei*, *Gymnothorax eurostus*, *Cirrhitus alternatus*, *Chaetodon multicinctus*, and *Acanthurus sandvicensis*), or neither, but not both, occurs at Johnston. That this proves nothing regarding the interbreeding potentialities of the two geographic forms has been discussed in an earlier paper (Gosline, In press). The failure to be able to determine whether interbreeding between the Hawaiian endemics and their Central Pacific counterparts would or does occur makes it impossible to prove whether the Hawaiain forms are full species or merely subspecies. This matter has also been discussed elsewhere (Gosline, *op. cit.*). The point here is that the failure to settle the matter has led to considerable zoogeographic misunderstanding concerning endemism in the Hawaiian inshore fish fauna. For example, Jordan and Evermann (1905: 32) conclude that about 50 per cent of the species of Hawaiian shallow water fishes are endemic; Fowler's (1928) treatment of the same fishes would give a far lower percentage of endemism, perhaps 15 per cent. This appears to be a disagreement concerning the number of endemic Hawaiian fishes, but in reality it is a difference in viewpoint regarding how many Hawaiian endemics should be treated as full species. That one viewpoint is correct and the other incorrect will probably never be proved. About all that can be said is that in general the Hawaiian offshoots of Indo-Pacific species are more distinctive than those that occur anywhere else. Since I believe that Jordan and Evermann's interpretation of Hawaiian endemism in fishes brings out this point more clearly than Fowler's and since no real intergradation can be demonstrated between Hawaiian and Central Pacific forms, it seems preferable to side with Jordan and Evermann.

Muraenichthys cookei–laticaudata

The Hawaiian form, *Muraenichthys cookei*, was described by Fowler (1928: 41, fig. 9). In 1943 Schultz (p. 53) synonymized Fowler's species with *Muraenichthys laticaudata* (Ogilby) described from Fiji. In 1949 Schultz and Woods (p. 172) recognized both species, differentiating them on the basis of the more anterior position of the dorsal origin in relation to the anus in *M. cookei*. The same basis of differentiation is used by Schultz (in Schultz, *et al.*, 1953: 72–73). No other differences between the two species are known. The relationship between the dorsal origin and the anus in specimens of the *M. cookei–laticaudata* complex from several localities is shown in Table 3. (In the table total lengths have not been given since there is no evidence of a change in the dorsal–anus relationship with growth.) Several points can only be suggested by this table since the within-sample variabil-

TABLE 3

THE RELATIONSHIP BETWEEN THE DORSAL ORIGIN AND THE POSITION OF THE ANUS IN SPECIMENS OF THE *Muraenichthys cookei–laticaudata* COMPLEX

Distances are expressed in thousandths of the standard length. Plus values indicate distances of the dorsal origin in front of the anus; minus values, distances behind the anus

SPECIES AND LOCALITY	NUMBER OF SPECIMENS	DISTANCE FROM ANUS	
		Average	Range
Muraenichthys laticaudata			
Marshalls	3	—26	—80 to + 11
Muraenichthys cookei			
Hawaiian Islands			
Midway	7	12	0 to + 23
Oahu	7	20	+ 3 to + 39
Johnston	12	50	+15 to +116

ity is high and the available specimens from any one locality few. First, the two "species" cannot always be separated on the basis of the dorsal origin, for the ranges of the Marshallese and Midway specimens overlap. Second, the Marshallese *M. laticaudata* is most like the Midway form of *M. cookei*, which becomes progressively more distinct at Oahu and Johnston. One would like to know the nature of the populations of this species complex at Wake, a northern outlier of the Marshalls and somewhat between the rest of the group and Midway, but it has never been taken there. One would also like to know about the Line Island populations, but again the species complex is unrecorded from there. In the absence of evidence from these rather crucial localities, one can only speculate that the complex moved into Hawaii from the west, becoming further and further differentiated as it moved down the chain and thence to Johnston. Whatever the derivation, the fact remains that in the habitat (Johnston) that most resembles that of the presumably ancestral *M. laticaudata* the differentiation is the greatest and in the habitat that least resembles the Central Pacific (Midway) the differentiation has been least. Thus the character by which *M. cookei* is distingguished from *M. laticaudata* cannot be explained as an adaptation to a cold-water environment; it would seem rather to be an instance in which differentiation has proceeded independently of the environment.

Gymnothorax eurostus–buroensis

The Hawaiian *Gymnothorax eurostus* is very similar to the Central Pacific species which has been called in recent years *G. buroensis*. Schultz (in Schultz, *et al.*, 1953: 120) has separated the two on the basis of minor color differences. The most important of these is the mottling of the lower jaw in *G. eurostus* as contrasted with the plain throat and lower jaw of *G. buroensis*. Unfortunately, *G. eurostus* at least is very variable in coloration, and almost any color character breaks down in some individuals. The color differentiation of the two species can, however, be supplemented by a number of morphological characters, but for each of these there are, again, individual exceptions. At any given size over perhaps 7 inches, *G. buroensis* is a chunkier fish, and the head especially is higher and blunter, but both species become more heavy-bodied with age. (This and other proportional characters do not seem worth stating quantitatively because of the difficulty of obtaining reliable measurements on morays.) The mouth of *G. buroenis* closes completely; that of *G. eurostus* does not, leaving a gap between the lips just ahead of the eye when the jaw tips are tightly closed. The length of the snout is usually less than the distance from the eye to the rictus in *G. buroensis*, greater in *G. eurostus*. The fifth pore from the front on the chin is usually behind the most posterior pore on the upper lip and behind the eye in *G. buroensis*, under or in front of the last pore of the upper lip and under the eye in *G. eurostus*. There are fewer teeth in the jaws of *G. buroensis* than of *G. eurostus*, but since adult morays usually lose teeth this character again does not seem to merit quantitative analysis. Finally, *G. buroensis* is definitely the smaller of the two species: the largest of several hundred specimens of *G. buroensis* taken by Schultz in the Marshalls (Schultz, *et al.*, 1953: 118) was about 13 inches; the largest of 20 specimens of *G. eurostus* taken by me in Johnston is 20 inches long. In sum then, the two species are rather easy to separate for anyone familiar with them, even though there is no single character on the basis of which it would be possible to correctly identify all specimens.

Due to the nature of the differences between the two species it can only be stated without adequate demonstration that all specimens of this complex from Johnston are typical *G. eurostus*. Specimens from Christmas, in the Line Islands to the south of Johnston, seem to be typical *G. buroensis*. All of the hundreds of specimens from the Hawaiian Islands seen by me, with one exception, are *G. eurostus*. The exception consists of specimens taken by Mr. Tinker of the Honolulu Aquarium from among the heavy fouling on the bottom of a barge that was put in drydock at Pearl Harbor (see Chapman and Schultz, 1952: 528, Edmondson, 1951: 212). The eel that dropped out of this fouling is a typical specimen of *G. buroensis*. Inasmuch as several other fishes, crustacea, and mollusks taken from this fouling have never been recorded elsewhere in Hawaiian waters, and inasmuch as the barge had been towed in from Guam, it seems logical to presume, despite Chapman and Schultz, that these alien forms came in with the barge from somewhere in the Central Pacific.

Kuhlia sandvicensis–marginata

Despite previous accounts (e.g., Fowler, 1949: 83) there seems to be only one species of *Kuhlia*, namely *K. sandvicensis*, represented in the Hawaiian chain. This species is closely related to *K. marginata* from the Central Pacific, with which it will here be compared. Before doing so it seems well to mention that from published accounts (e.g., Ikeda, 1939: 131–158) *K. boninensis* from the Bonin and Riu Kiu Islands also seems to be near *K. sandvicensis*.

According to Schultz (in Schultz, *et al.*, 1953: 325) *K. marginata* differs from *K. sandvicensis* in having somewhat higher average pectoral and dorsal counts. However, the two species also differ in the number of gill rakers, and it is these that will be emphasized in this analysis.

In the number of dorsal rays, my counts of *K. sandvicensis* agree more closely with Schultz's counts of *K. marginata* than with his data for *K. sandvicensis* (Table 4). Under the circumstances there seems no point in following the analysis of this character further.

The total pectoral ray counts in certain samples of the *K. sandvicensis–marginata* complex are summarized in Table 5. Several aspects of this table warrant discussion. In the

TABLE 4

DORSAL SOFT RAY COUNTS IN THE *Kuhlia sandvicensis–marginata* COMPLEX

SPECIES AND LOCALITY	NUMBER OF SPECIMENS	AVERAGE COUNT
K. sandvicensis		
Hawaiian Islands		
Midway	25	11.08
French Frigate	5	11.00
Kauai	25	11.08
Oahu	25	11.04
Oahu (Schultz)	9	11.55
K. marginata		
Johnston (Schultz)	2	11.00
Marshalls (Schultz)	10	11.00

first place the several small samples available from Midway vary considerably in average count. What this means is not clear, but it has prevented me from placing too much faith in the results of single larger samples from elsewhere. If one were to exclude the samples from the low Hawaiian Islands (Midway, Lisianski, and French Frigate) one would obtain a correlation between increase in pectoral count and decrease in water temperature for the species complex. On the other hand, if one considered the samples of *Kuhlia sandvicensis* alone, one would obtain a correlation in the reverse direction. An attempt to explain these contradictory trends will be made after consideration of the gill-raker data. Meanwhile, it may be noted that the Johnston fishes appear to be of almost pure Central Pacific stock.

Before proceeding with the gill-raker information, three features should be noted. In the first place, as Schultz (1943: 99) has observed, the young of *Kuhlia* have fewer gill rakers than the adult. By plotting the number of gill rakers against standard length in certain large Hawaiian samples, it was determined that *K. sandvicensis* obtains approximately its full gill-raker complement by about 40 millimeters in standard length. Consequently no fish smaller than 40 millimeters were used in the data which follow. The second point regards the method of making counts. In *Kuhlia* the most anterior one of two rakers frequently taper to almost nothing, and it seems preferable to count only the developed gill rakers. Here, then, only the pectinate rakers are counted; the shorter, nob-topped rakers are omitted. Even this restriction leaves some specimens in which the count remains somewhat questionable. To check the consistency in my own counting, the gill rakers in a sample of 37 fish were recounted at the end of a year. The original count gave an average of 24.41, the later count, 24.57. These and all other counts used here are only those below the angle (excluding the raker at the angle).

TABLE 5

TOTAL PECTORAL RAY COUNTS IN SPECIMENS OF THE *Kuhlia sandvicensis–marginata* COMPLEX

SPECIES AND LOCALITY	NUMBER OF SPECIMENS	AVERAGE COUNT
K. sandvicensis		
Hawaiian Islands		
Midway (Mar., 1949)	7	14.57
Midway (July, 1949)	12	14.91
Midway (June, 1950)	6	14.33
Midway (May, 1951)	3	15.00
Midway (all specimens)	28	14.72
Lisianski	3	14.33
French Frigate	5	14.60
Kauai	10	14.80
Oahu	25	14.76
Oahu (Schultz)	17	15.00
Hawaii	22	15.00
K. marginata		
Johnston	9	14.00
Line Is.: Palmyra	2	14.00
Wake	20	14.00
Marshalls (Schultz)	10	13.71

Pectinate gill rakers on the lower limb of the first arch range from 22 to 28 in my samples of *K. sandvicensis*, from 24 to 29 in the smaller numbers of *K. marginata* examined. It seems well to discuss the *K. sandvicensis* samples first, as these are both the largest and the most numerous. In the first place it seems as if those samples containing small fish have somewhat lower average counts than the samples with large fish (Table 6). Perhaps the gill raker number does continue to increase above 40 mm.

With this in mind, the pairs of samples from the same island may be compared. The two Oahu samples were taken in different years from exactly the same tide pool. The difference between the means of these two samples is 0.41. The two samples from Hawaii are of an entirely different sort. One was taken from fresh water, the other from the sea. The difference between the means of these samples is 1.50 gill rakers, though part of this difference may be attributable to the different sized specimens in the sample. At any rate, it seems from the above data that (presumably) environmental differences within areas may play a considerable role in the differentiation of gill raker counts, and this must be kept in mind in assessing the biological significance of the difference between samples.

Even allowing for this variability within areas, the gill raker counts for *K. sandvicensis* at Midway seem to be considerably higher than for other areas. The increase in Midway counts over those of Pearl and Hermes reef some 90 miles away is especially curious.

Among the samples of *K. marginata* about all that can be said is that the counts for the Johnston and Wake specimens seem to be particularly high. On the other hand the few counts from Penrhyn, about as far south of the equator as Johnston and Wake are north, are low. Any attempt to correlate gill-raker counts with water temperatures in this species complex on the basis of the present material seems fatuous.

Summing up the data for the *Kuhlia sandvicensis–marginata* complex, it may be said that the Johnston and Wake samples show absolutely no indication of introgression from the Hawaiian species so far as gill-raker counts are concerned. Conversely, the samples from the high Hawaiian islands show no sign of intermixing from *K. marginata*. However, the low Hawaiian island samples, particularly those from Midway, show a trend toward the southern form. Since Midway has the water temperatures and total environment least like those of the areas in which *K. marginata* lives, the similarity of the Midway *K. sandvicensis* to *K. marginata* can best be explained by introgression from the latter species. Whether such introgression is brought about through specimens of *K. marginata* coming in from Johnston, Wake, Marcus or elsewhere remains unknown.

TABLE 6

THE NUMBER OF PECTINATE GILL RAKERS ON THE LOWER LIMB OF THE FIRST GILL ARCH IN SAMPLES OF THE *Kuhlia sandvicensis–marginata* COMPLEX

SPECIES AND LOCALITY	NUMBER OF SPECIMENS	AVERAGE COUNT	STANDARD DEVIATION	AVERAGE STANDARD LENGTH IN MM.
K. sandvicensis				
Hawaiian Islands				
Midway (July, 1949)	25	25.40	1.24	61.0
Midway (June, 1950)	29	25.28	0.80	over 100*
Pearl and Hermes	22	24.18	0.73	over 100*
Lisianski	39	24.41	0.75	over 100*
French Frigate	5	24.20		61.8
Kauai	25	24.64	1.25	135.6
Oahu (Waimea, 1948)	37	24.41	0.75	69.6
Oahu (Waimea, 1949)	33	24.82	0.73	62.6
Hawaii (Puna Coast)	22	24.77	0.87	47.0
K. marginata				
Johnston	9	27.33	0.50	180.0
Line Is.: Palmyra	5	26.40		156.6
Phoenix Is.: Canton	3	26.00		198.3
Cook Is.: Penrhyn	6	25.67		71.8
Wake	18	27.20	1.24	121.0
Marcus	5	26.00		84.8

* Large specimens discarded in field.

In view of what has been said above, a hypothetical explanation can be given for the relationship between pectoral counts and sea temperatures. The basic assumption is that pectoral counts in this species complex increase with decreasing temperatures. In partial isolation the Hawaiian island populations would then have developed distinctly higher pectoral counts. These would be higher at Midway at the northern end of the chain than at Hawaii at the southern. However, recent introgression from *K. marginata* at Midway could have upset this trend within the Hawaiian chain, giving rise to the reversed picture for pectoral counts within the Hawaiian Islands shown in Table 5.

The fact remains that there is more difference between the *Kuhlia* populations in Johnston and Hawaii, which are almost similar in latitude, than between those of Johnston and Midway, which are very different. The conclusion seems inescapable that if members of the Johnston populations have entered the Hawaiian Islands at all, they have come in via the low northern islands. Why the Central Pacific form of *Kuhlia* rather than the endemic Hawaiian form should be present at Johnston remains a mystery. It does, however, bear out the point, previously established, that some elements of the Johnston biota have entered from the south.

Cirrhitus alternatus–pinnulatus

The two forms in this complex have recently been differentiated by Schultz (1950: 548), but entirely on the basis of coloration, the Hawaiian *C. alternatus* lacking the brown spotting of the Central Pacific species. A check of the usual meristic characters in specimens from Hawaii, Johnston, and Christmas (in the Line Islands) shows no significant differentiation. As Schultz has already pointed out (*loc. cit.*), the Johnston specimens agree completely with the Hawaiian form.

Chaetodon multicinctus–punctato-fasciatus

This species pair has been separated by Woods (in Schultz, *et al.*, 1953: 571, 575, 595) on the basis of coloration and certain counts. The color differences lie chiefly in the nature of the vertical dark bars on the nape and caudal peduncle. The fin ray differences are shown in Table 7. Woods (*loc. cit.*) has also used scale counts, but I have not been able to make sufficiently accurate scale counts in this species to be worth recording.

The Johnston specimens agree with the Hawaiian form in both color and counts.

Acanthurus sandvicensis–triostegus

The *Acanthurus triostegus* complex lends itself admirably to geographic analysis for two reasons. First, its forms are abundant and ubiquitous throughout much of the tropical Indo-Pacific, and, second, they differ in characteristics that are easily seen and calibrated. A preliminary analysis of geographic variation in this complex has recently appeared (Schultz and Woods, 1948: 248–251). According to these authors two species are represented: *Acanthurus sandvicensis* in the Hawaiian Islands and at Johnston, and *A. triostegus* throughout the rest of the area. The differences between these two lie primarily in the shape and extent of the mark below and at base of the pectoral, secondarily in the higher average fin counts of the Hawaiian species.

The Johnston Island population, judging from 21 specimens taken in three Johnston localities, differs in no way that I can determine from the Hawaiian form. If there is any admixture of *A. triostegus* genes in these Johnston specimens, it is not apparent. If, however, populations of the *A. triostegus* complex from the next island groups to the south of Johnston are examined an occasional specimen turns up with more or less strong traces of the Hawaiian pectoral base marking. For a study of possible intergradation between the Hawaiian *A. sandvicensis* and the Indo-Pacific *A. triostegus* it seems advisable therefore to focus attention not on Johnston but on the Line and Phoenix Islands to the south of Johnston.

TABLE 7

FIN COUNTS IN SPECIMENS OF THE *Chaetodon multicinctus–punctato-fasciatus* COMPLEX

SPECIES AND LOCALITY	DORSAL SOFT RAYS					ANAL SOFT RAYS			PECTORAL*		
	22	23	24	25	26	17	18	19	13	14	15
C. multicinctus											
Hawaiian Islands (Woods)			1	7			3	6		5	4
Honolulu............			1	4	1		3	3		3	
Johnston...............			1	1	1		1	2		3	
C. punctato-fasciatus											
Marshalls (Woods).......	1	2	6	1		4	6		2	6	

* Splint at top of pectoral fin not included.

In color pattern three rather distinctive types have been distinguished in the Central Pacific. (1) In the Marshalls (according to Schultz and Woods, *op. cit.*, p. 250, table 1) specimens of *A. triostegus* almost always have a single spot at the upper end of the pectoral fin base. In addition (Schultz and Woods, in Schultz, *et al.*, 1953: 625) the black marking on the caudal peduncle is "represented by a spot on dorsal and ventral sides, or a saddle, sometimes absent except for a small spot on dorsal surface only, never completely across side of caudal peduncle." (2) *Acanthurus sandvicensis* consistently has a dark bar across the pectoral base, which is continued downward and somewhat backward on the body. On the caudal peduncle there is a black saddle which extends one third to one half way down the side of the peduncle; there is no spotting below this saddle. (3) In the Marquesas (according to Schultz and Woods, 1948, *loc. cit.*) *A. triostegus* consistently has two spots at each pectoral base, one at the upper part of the base as in the Marshallese form, and another on the body just below the base. These two spots are connected in the young. The caudal saddle in the Marquesan specimens is usually as in the Marshallese form but, in 6 out of 18 specimens, "extending down sides of caudal peduncle and joining with spot on lower sides" on at least one side of the body (Schultz and Woods, 1948, *loc. cit.*). All of the three color types cited above may be found in specimens from Line and Phoenix Island samples in addition to variants not apparently found elsewhere. Quite frequently markings characteristic of two different races occur on the two sides of the same Phoenix or Line Island fish.

If a stripe running down on to the body below the base of the pectoral fin is designated as A, a single spot on the upper part of the pectoral fin base as B, two spots, one on and one below the fin base as C, and a bar across, and limited to, the fin base as D, Table 8 may be prepared. (The A, B, C, and D types are essentially those similarly designated in Schultz and Woods (1948: 249 and in Schultz, *et al.*, 1953: 625). Actually the four types are not sharply distinct in Phoenix and Line Island fishes. In these areas the A type band extends only slightly below the pectoral base (about as in type E of Schultz and Woods and not well below as in *Acanthurus sandvicensis*) and thus can only be distinguished by definition from D. Furthermore in a few specimens the lower part of the stripe of A tends to become separate and thus grades into C. Finally an elongate spot (B) grades into a bar (D).)

From this table it may be seen that between these two samples all combinations of the different types of pectoral marking may and do occur on opposite sides of the same fish. Indeed, 16 out of 60 specimens have different types of pectoral markings on the two sides of the body. The instability in these populations of the types of pectoral markings that are elsewhere nearly constant is excessive.

If one considers B to be the pure Marshallese form, C to be the Marquesan, and A and D a tendency toward the Hawaiian species, then the table may be recalculated as is done in Table 9.

Table 9 demonstrates the unity in pectoral markings of the two samples from the northern Line Islands (Christmas) and the southern Phoenix Islands (Hull). These two islands are, incidentally, some 800 air miles from one another. Also, if types B and D really are a tendency towards *A. sandvicensis*, some indication of intergradation with the Hawaiian species seems present in both samples.

Summarizing the data on pectoral markings in the Phoenix–Line populations, it may be said that these contain to some degree all the marking types to be found in the more constant races to the west (Marshallese), north (Hawaiian), and southeast (Marquesan).

In regard to caudal peduncle markings, a similar concentration of variability in the Phoenix and Line Island samples could probably be demonstrated. However, an analysis of the caudal markings suffers from the two facts that the Marshallese and Marquesan races are not particularly constant in this feature and that the Hawaiian marking is to some extent intermediate between the Marquesan and Marshallese pattern. Suffice it, then, to say here that the same bilateral asymmetry in the coloration on the caudal peduncle takes place as occurs in the pectoral marking, that there does not seem to be any correlation between the shape of the marks on the caudal peduncle and those at the pectoral bases, and finally that there are again all gradations between the various types of caudal markings.

The other feature used by Schultz and Woods (*op. cit.*) in separating the forms of the *Acanthurus triostegus* complex is the dorsal, anal, and pectoral fin counts. The Hawaiian species was found to have higher average sample values for each of these fins than samples from elsewhere. Schultz and Woods go on to note that the somewhat lower water temperatures of the Hawaiian area may be responsible for this.

Dorsal, anal, and pectoral counts of certain samples from the Hawaiian, Line, and Phoenix Islands, along with the average annual water temperatures (as calculated from Charts II and III at the back of Sverdrup, Johnston, and Fleming, 1946) are shown in Table 10. Several points about this table need discussion. The first regards variation within areas. Thus, two samples from the single island of Oahu have an average difference of nearly 0.2 of a dorsal ray. Indeed, one suspects that different populations from the same area might differ by perhaps 0.3 dorsal ray, 0.2 anal ray, and 0.1 pectoral ray, though available data is insufficient to prove this. At least nothing less than such amounts should be considered geographically significant. Second, the various island groups investigated seem to have rather different average counts, as summarized in Table 10. The Phoenix (Hull Island) sample, well to the south of the Line Islands and still farther away from Hawaii seems to be intermediate between the Line and Hawaiian Island samples. Another Phoenix Island lot counted by Schultz and Woods (1948: table I) indicates the same thing. Certainly, no genetic intermixing between the Hawaiian and Line Island samples is indicated. If one attempts to explain the change in average count by temperature effect, the Line Island samples create the same stumbling block as for introgression, for temperatures in the Phoenix Islands seem to be higher (and should therefore give lower, not higher, average counts than for the Line Island lots).

Summarizing for the *Acanthurus sandvicensis–triostegus* complex, the following points may be made. There is no sign of intergradation between *A. sandvicensis* and *A. triostegus* at Johnston; the pure Hawaiian form is represented there. In the Line and Phoenix Island samples there is some indication of the *A. sandvicensis* pectoral marking in some speci-

TABLE 8

TYPES OF MARKINGS AT PECTORAL BASE IN PHOENIX AND LINE ISLAND SAMPLES OF *Acanthurus triostegus*
For explanation of lettering, see text

LOCALITY	AA	AB	AC	AD	BB	BC	BD	CC	CD	DD
Line Is.: Christmas	1	0	1	1	15	1	4	3	0	1
Phoenix Is.: Hull	4	2	0	1	17	2	3	2	1	1

TABLE 9

TYPES OF MARKINGS AT PECTORAL BASE IN PHOENIX AND LINE ISLAND SAMPLES OF *Acanthurus triostegus*

LOCALITY	"MARSHALLESE"	"MARQUESAN"	"HAWAIIAN"
Line Is.: Christmas	35 (65%)	8 (15%)	11 (20%)
Phoenix Is.: Hull	41 (52%)	7 (11%)	18 (27%)

mens. That introgression of *A. sandvicensis* genes into these populations has occured via passage of Hawaiian individuals through the Line Islands is contra-indicated by the average fin counts of Line Island samples.

Results of the Species Analyses

Though the nature of the available material precludes very extensive cross comparisons between species, a certain amount of integration between the results of the various species can be made.

The first point regards the nature of the morphological distinctions of the Hawaiian endemic forms. In an earlier paper (Gosline, In press) it was stated: "In morphological features the Hawaiian endemic fishes show no pattern of divergence from their Central Pacific relatives." However, in view of Strasburg's recent paper (1955) demonstrating that in the *Istiblennius edentulus* complex there is a rather close correlation between fin ray count and water temperature, it seems well to reinvestigate this statement. Among the six species pairs dealt with here, four differ in coloration, three in meristic counts, one in the position of the dorsal origin, and one in the shape of the head. Of those differing in color, *Gymnothorax eurostus* is separable primarily on the basis of the mottling of the throat, *Cirrhitus alternatus* in the absence of brown spots on the body, *Chaetodon multicinctus* in the presence of more prominent barring on the nape and caudal peduncle, and *Acanthurus sandvicensis* in the long curved streak below the pectoral base. There seems to be no pattern of differentiation here. However, a pattern does emerge from the meristic data. Of those species pairs differing in meristic characters, two of the Hawaiian endemics have more pectoral rays (*Kuhlia sandvicensis* and *Chaetodon multicinctus*), two have more dorsal and anal soft rays (*Chaetodon multicinctus* and *Acanthurus sandvicensis*), and one has *fewer* gill rakers (*Kuhlia sandvicensis*). Thus for fin rays, if not for gill rakers, there does seem to be a trend toward higher meristic counts in these Hawaiian endemics. Other species showing the same trend that are not dealt with here are *Istiblennius zebra* (see Strasburg, *op. cit.*) and *Dascyllus albisella*. However, what has just been said should not obscure the fact that there are many species in which the Hawaiian form shows no increase in counts and at least a few in which a decrease occurs. Thus the Hawaiian trichonotid *Crystallodytes cookei* differs from its Phoenix Island counterpart only, so far as known, in having *fewer* dorsal and anal rays (Schultz, 1943: 266), and the Hawaiian gobioid *Kraemeria bryani* differs

TABLE 10

Fin Counts for Certain Samples of the *Acanthurus sandvicensis–triostegus* Complex

For the counts averages are given above and standard deviations below in parentheses. No standard deviations were calculated for the counts drawn from Schultz and Woods (1948: table 1) as these appear to represent combined samples

LOCALITY	AVERAGE ANNUAL SURFACE WATER TEMPERATURE	NUMBER OF SPECIMENS	SOFT DORSAL RAYS	SOFT ANAL RAYS	TOTAL PECTORAL RAYS
Hawaii: Midway	22.0° C	18	23.33 (±.57)	20.67 (±.57)	15.89 (±.33)
Hawaii: Oahu (tide pool on exposed NW coast)	24.5	20	23.45 (±.55)	20.75 (±.58)	15.85 (±.36)
Hawaii: Oahu (reef-enclosed bay)	24.5	46	23.28 (±.62)	20.67 (±.47)	15.83 (±.38)
Hawaii and Johnston (from Schultz and Woods)		32	23.59	20.84	15.84
Johnston	26.0	21	23.47 (±.60)	20.67 (±.80)	15.81 (±.40)
Line: Palmyra	26.8	36	22.78 (±.59)	19.58 (±.92)	15.50 (±.50)
Line: Christmas	26.1	26	22.46 (±.51)	19.46 (±.58)	15.46 (±.51)
Phoenix: Hull	27.3	33	23.03 (±.52)	20.00 (±.49)	15.45 (±.50)
Phoenix (from Schultz and Woods)		11	23.09	20.36	15.37*
Guam, Marshalls (from Schultz and Woods)		21	22.81	20.14	15.19

* Based on 16 specimens.

from its tropical relative *K. samoensis* most significantly in the *lower* number of pectoral rays (Schultz, 1943: 262).

Zoogeographically there are few definite conclusions that can be drawn from the species analysis, though there are several indications. One of the species, *Kuhlia marginata*, has obviously come to Johnston from the south; the other five have come down from the north. The southern *Kuhlia* shows distinct signs of having introgressed into the northwestern Hawaiian Island populations of *K. sandvicensis*, though whether this has been due to immigration from Johnston or elsewhere remains unknown. Since, however, the prevailing current system around Johnston is from east to west, and even northwest, it seems probable that any migration from Johnston would reach the western leeward Hawaiian Islands rather than the eastern windward islands. Because of this same current system, any Hawaiian fishes arriving at Johnston would probably have come in from the eastern rather than the western islands, and this is what appears to have happened with *Muraenichthys cookei*, judging from the data presented on that species. That Hawaiian endemics, such as *M. cookei*, have gotten from the Hawaiian Islands to Johnston seems certain. That Johnston fishes actually ever got to Hawaii remains unproven.

ZOOGEOGRAPHIC CONCLUSIONS

Although it may be repetitious, it seems well to draw together the results of the second half of this paper for the sake of those who got lost among the pectoral markings of *Acanthurus* or elsewhere.

The Johnston fish fauna is made up of four components (Fig. 4): endemics; fishes that have made Johnston a stopping point on their migrations from the south; fishes that have found Johnston as a way point in their southward travels; and pelagic fishes to whom Johnston is of little or no significance. The last category, which undoubtedly merges into the second and third, has been excluded from consideration in the present paper. The first is made up of only two species which may simply have been as yet unrecorded elsewhere; in any case, there is very little endemism at Johnston. Species that must have come in from the south, since they are as yet unrecorded in Hawaii and those known to have come in from the north, the "Hawaiian endemics," are represented in Johnston in about equal number. In terms of percentages, however, the proportion of the Hawaiian endemic fauna that reached Johnston is far higher than the proportion of the Central Pacific fauna that reached Johnston but not Hawaii. For this reason it is preferable to consider Johnston as an outlier of the Hawaiian faunal area rather than as a peripheral component of the Central Pacific faunal area.

There is no known intergradation between Hawaiian endemics and their Central Pacific counterparts at Johnston. If the Central Pacific form is represented at Johnston it is there in its pure form and the Hawaiian counterpart is absent, and vice versa.

Since many "Hawaiian endemics" are present at Johnston, it is certain that some species at least have traveled from Hawaii to Johnston. It is, however, not proven that any Johnston fishes ever got to Hawaii; nor is it proven that they did not. Consequently, the role that Johnston may have played in the development of the Hawaiian fish fauna remains in doubt. If, however, one rejects Johnston as the stepping stone by means of which the Hawaiian fishes arrived, then one is driven back on immigration routes that, at the present time, are at least equally implausible and unproven.

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An Interpretation of the Structure and Distribution of Cnidae in Anthozoa

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An Interpretation of the Structure and Distribution of Cnidae in Anthozoa

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DURING the past century many publications on coelenterate cnidae (nematocysts) have appeared, but, apart from the major paper of Weill (1934) and two of Carlgren (1940 and 1945), they do not have direct bearing on this study or are only of historical interest. An excellent review of the literature previous to 1934 can be found in Weill's monograph. In this treatise on the cnidae Weill has associated the nematocyst types of earlier authors with the categories of his own system of classification. In his scheme of nomenclature the cnidae are divided into the two general groups, nematocysts and spirocysts. The spirocysts are not subdivided, being retained by Weill as a category which closely follows the definition of Bedot (1896). The nematocysts, on the other hand, he divided into astomocnides and stomocnides. In turn, the stomocnides are divided into haplonemes, heteronemes, and rhopaloides. The haplonemes and heteronemes (only stomocnides occurring in the Anthozoa) he arranged in a succession of smaller and more specific units. The definitive appellatives of these two groups—basitrichs, microbasic mastigophores, micro- and macrobasic amastigophores, holotrichs and atrichs—along with the spirocysts, are those that subsequently have been used to refer to Anthozoan cnidae. Carlgren (1940) subdivided Weill's microbasic mastigophores into macrobasic *b*-mastigophores and microbasic *p*-mastigophores. The nomenclature of Weill, as modified by Carlgren, is used in this paper with the exception that it is proposed to eliminate two categories (microbasic and macrobasic amastigophores) and to add two new ones (microbasic *q*-mastigophores and macrobasic *p*-mastigophores).

The nomenclature of the categories of cnidae is not so much the concern of this paper as are the finer diagnostic structures. The current nomenclature is descriptive and, with the exceptions of the amastigophores, microbasic *q*-mastigophores, and macrobasic *p*-mastigophores, sufficient. With the same exceptions, the definitions of the categories are detailed and accurate. It is only the association of many of the nematocysts with the definitions that is in error, the errors being the result of misinterpretation of the fine structure of the nematocysts. For example, the long, thin cnidae with completely coiled capsular content that are so characteristic of the marginal spherules (acrorhagia) are commonly considered by actinologists to be atrichs, and only when the armature of the tube is very coarse do they recognize them as holotrichs. Actually, armature is always present on the tube but sometimes is very fine and care must be taken to resolve it under the microscope.

A somewhat different case is that of a nematocyst type, characteristic of the Boloceroididae, which usually is referred to the microbasic amastigophores. Here even a careful examination of the ends of the shafts of many of these nematocysts, when they are exploded in fresh preparations, does indeed indicate that they are amastigophoric (lacking a thread). However, if observations are extended to the unexploded nematocysts and if the process of uncoiling in this particular type is carefully followed, an entirely different picture emerges. These nematocysts characteristically have a very thin thread which forms a loop between the notch at the end of the shaft and the blind end of the capsule to which the distal end of the thread apparently adheres. Upon evagination of the capsular content, the thread usually breaks at the point of attachment with the shaft and remains in the capsule. However, it occasionally evaginates with the shaft. In any case, these nematocysts do possess a thread and should be classed as microbasic *p*-mastigophores, not microbasic amastigophores.

If the cnidae are to have value in systematics they must be susceptible of consistent and reasonably rapid identification. This is possible only when the absolute diagnostic characteristics of the cnidae have been determined. Ideally these characters should be distinguishable either in the intact or exploded state. Thus, through re-evaluation of the present categories of nematocysts (based on new interpretations of their finer structures) it becomes possible to associate the nematocysts more precisely with the existing definitions.

No attempt is made in this paper to go into the complete structure of the cnidae or to point out all the confusion in previous publications. Only those aspects of the cnidae which appear to be useful in systematics are covered. Most of the data used in the preparation of this paper were obtained from examination of unpreserved material. All of the major groups of the Anthozoa have been examined, except the tribus Protantheae and order Ptychodactiaria, but the cnidae described and figured for these groups by other investigators have been readily recognized and are considered. Most of the figures of capsules are drawn to scale but the tube and armature are not. The details of the figures are accurate with the exception that only one of the three bands of armature has been drawn on the tubes. The capsule sizes are referred to only when pertinent to the discussion.

General Considerations

The cnidae are the intricate, non-living products of certain apparently undifferentiated coelenterate cells. It is not known whether one cell is capable of producing more than one nematocyst or more than one kind of nematocyst. During the early stages of cnidogenesis the types of nematocysts contained within the secreting cells are almost indistinguishable one from the other. It is only during the later stages that the great variety of form and size of the nematocysts becomes apparent. It is these cnidae of variable size and structure which, when evaluated and classified, lend themselves so well to systematics.

The size of the capsule was probably the first feature of the cnidae used in classification of species of coelenterates. Many investigators who make no attempt to give the cnidom for a species will list sizes of the more conspicuous categories of cnidae. Carlgren (1900), referring to Actiniaria, pointed out that "no description of a species is complete unless it includes notes on the size of the nematocysts." However, neither size of nematocysts for the larger taxonomic groups nor randomly selected measurements of nematocysts from a species are necessarily of taxonomic value. To be diagnostic the measurements of nematocysts must be taken from all the major kinds that comprise the cnidom of the species. Frequently, obviously aberrant dwarfs or giants appear in all the categories, but they are of no importance to the diagnosis. Equally as important as knowing the sizes of all the categories of nematocysts is the knowledge of which specific organs or parts of organs were the source of the measured nematocysts. For example, in *Rhodactis* sp. macrobasic *p*-mastigophores (in this case the holotrichs of Weill and

Carlgren) from the distal parts of the filaments are more than twice the size of those from the proximal parts of the filaments. Also essential is the knowledge of degree of maturity of the animal from which the nematocysts are examined. Young animals frequently possess categories of nematocysts that are absent in adults, and also the sizes of those kinds that are present in both often differ markedly.

The nomenclature of Weill and Carlgren is based solely on the capsular content, but in specific instances the shape of the capsule has utility in the scheme of classification. The capsule, in silhouette, may have the shape of a straight rod, a bent rod, a bottle; it may be lenticular, pyriform, ovoid, spherical, or any variation of these forms. Sometimes the shape of the capsule is very distinctive, e.g., the bottle-shaped microbasic *b*-mastigophores of some species of *Actinothöe*. This feature alone may not be significant in the total cnidom of the genus but coincident with other characteristics it is of great help in recognizing the species.

A trivial detail but one related to capsular structure is the "operculum." Weill (1934) is the only recent author to make a point of it but he does not make clear what he means by the term. He draws it (p. 23, Fig. 10*a*) as a cap over the aperture of the undischarged nematocyst, but if this were true it could not possibly persist in the discharged state as he has drawn it (p. 23, Fig. 10*b*). If he implies there is a cap over the aperture, he is in error, and if he means there is a thickened rim or flange around the aperture, his choice of the term, operculum, is misleading. I have never seen evidence of an operculum on an anthozoan nematocyst. If there were an operculum (cap) present, the tip of the shaft would not protrude beyond the aperture of the capsule as it commonly does in certain kinds of nematocysts (Fig. 1, *f*). All evidence suggests that the aperture is surrounded by a thickened ridge or flange at the juncture of the capsule wall with the tube (Fig. 1, *f,g*).

The capsular content exhibits by far the greatest variation of form, and for this reason the nomenclature is based on it. In a limited sense the capsular content is the tube. Granules and fluids contained in the capsule with the tube bear little significance to this study. The tube of the nematocyst may be short or long and may be, with respect to diameter, undifferentiated or divisible into a portion of greater diameter (the shaft) and a portion of lesser diameter (the thread). The tube may be smooth (?) or bear three helically-coiled bands of armature which may extend throughout its length or be restricted to some fraction thereof. The armature, in turn, may vary from very long and coarse to nearly imperceptible spines. The armature varies in length on different regions of the tube of a single nematocyst as well as between categories of cnidae. The presence of armature on the tube is so characteristic for most nematocysts (I have found it throughout the length of all types of tubes except the terminal portion of basitrichs and the entire tube of atrichs) that it may very well be that all nematocyst tubes are or have been armoured throughout their length. It seems that some atrichs in the Ceriantharia and Corallimorpharia may very well be macrobasic *p*-mastigophores which have lost their armature. The structure of the tube and its armature is more fully covered in the discussion of the categories of cnidae.

There are two opposing opinions on the inherent character of the undischarged tubes of nematocysts which have a distinct shaft, but both are somewhat vague as to details. It may, therefore, be advantageous at this time to explain the configuration of these tubes. Moebius (1866), Bedot (1886), and Gosse (1860), in particular, have indicated that, in those nematocysts with a shaft of considerably greater diameter than the thread, the shaft is folded within itself (Fig. 1, *a*). If

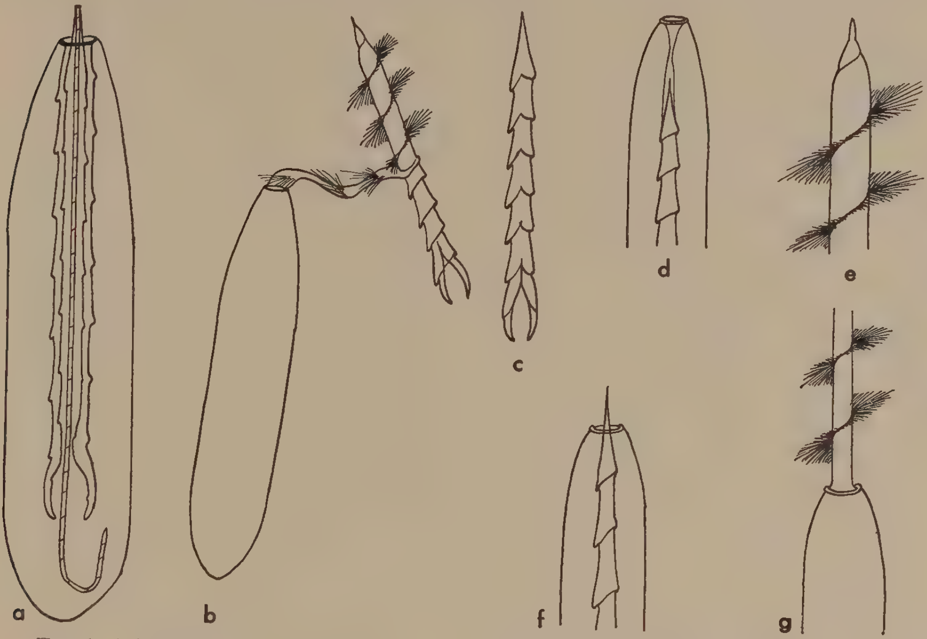

FIG. 1. Microbasic *p*-mastigophores. (*a*) diagram of invaginated and folded shaft with thread; (*b*) crushed specimen with proximal shaft wall torn away exposing infolded distal part of shaft; (*c*) isolated, invaginated shaft showing angle of folded armature is several times greater than angles of the shaft's point and notch; (*d*) proximal portion of invaginated shaft between the capsule aperture and point of the shaft; (*e*) example of a vestigial thread; (*f*) point of shaft protruding beyond the capsule aperture; also, showing flange (rim) around aperture; (*g*) showing persistence of flange after evagination of shaft.

the shaft is thus folded the thread (always present?) will then be attached at the point of the shaft which is usually in the aperture of the capsule. Weill (1934), in describing the type morphology of a nematocyst (microbasic *p*-mastigophore), has rejected the interpretations of these earlier investigators. He (p. 23, Fig. 10*a*) shows the shaft to be inverted but not folded and the thread to be attached to the end of the shaft farthest from the capsule aperture. Figure 1, *b* illustrates a crushed nematocyst in which the shaft, although partly attached, has been forced out through a split in the capsule. In this instance part of the shaft has also split and pulled away, exposing the folded section. Accidentally crushed preparations like Figure 1, *b* conclusively show the shaft to be folded as well as invaginated. Further substantiating evidence is that encountered in some large macrobasic *p*-mastigophores in which the distal end (the point) of the shaft does not reach the aperture of the capsule (Fig. 1, *d*). Here a tube (the base of the shaft) can be seen extending from the aperture, sometimes for a considerable distance, to the point of the shaft.

Weill (1934, p. 23, Fig. 10*a*) shows the point at the aperture end of the undischarged shaft and the notch at the opposite end to be the result of the armature folded within the tube. His figure is without doubt that of a microbasic *p*-mastigophore but is not an accurate depiction. Figure 1, *c* is more nearly the configuration of an isolated, undischarged shaft of a microbasic *p*-mastigophore. In this figure it can be seen that the angles formed by the folded armature are decidedly less acute than the angles of the notch and point of the shaft. This observation and the fact that the point does not fray out when protruding beyond the aperture indicates rather conclusively that the point and the notch of the tube are not configurations of the armature. There is strong evidence, then, that in those nematocysts with a shaft of considerably greater diameter than the thread the shaft is both invaginated and folded back within itself. This folding of the shaft brings the tip of the shaft (the juncture with the thread) to a position in or near the capsule aperture. The categories of nematocysts exhibiting this phenomenon are micro- and macrobasic *p*-mastigophores and microbasic *q*-mastigophores. All other types of nematocysts have a tube which is simply inverted within the capsule.

The staining reactions exhibited by cnidae suggest that there are chemically different types. The spirocysts, for example, are well known for their affinity for acid dyes, and equally well known is the affinity of the "nematocysts" for basic dyes. There are, however, nematocysts which are completely refractory to both acid and basic dyes. Other evidence suggesting chemically different types of nematocysts is that of the variation in their toxicity. Different categories of cnidae, and even the same morphological types from different species, may produce markedly different toxic reactions in other animals. So little is now known about the chemical nature of nematocysts that attempted use of their chemical characteristics in classification would only be confusing.

All the previously mentioned characteristics of the cnidae mean little in a systematic diagnosis unless the distribution of the cnidae is also given. Considering first the distribution of the cnidae in the organs of Anthozoa, most of the organs of both entodermal and ectodermal origin contain nematocysts. Nematocysts are not an intrinsic feature of the mesoderm. Almost every category of cnidae occurs in both the ectoderm and entoderm in at least some species, but it is doubtful if this can be said of the spirocysts. When spirocysts are described from entodermal organs, such as filaments, they are almost certainly contaminants. Some organs of a species may contain several categories of nematocysts. For example, the marginal spherules (acrorhagia) of *Phymactis clematis* possess holotrichs, microbasic *b*-mastigophores, and spirocysts. On the other hand, an organ may contain no nematocysts (the ectoderm of the column of some Alcyonaria) or only one kind (microbasic *p*-mastigophores in the acontia of *Sagartiomorphe*). In deriving the cnidom for a species it is thus most important to consider the types of nematocysts for all organs of the animal. When the cnidom is well known for all species of a genus or family, it is frequently found that the distribution, together with morphological characteristics, of the cnidae is also diagnostic for the genus or family. As an example, I re-cite the situation of the peculiar microbasic *p*-mastigophores found in all species of the family Boloceroididae. On the basis of morphological characteristics, Carlgren (1924) assembled the genera, *Boloceroides* and *Bunodeopsis*, into the family Boloceroididae. Now we have the additional evidence of a carefully determined cnidom which substantiates his phylogenetic arrangement.

Carlgren (1945, pp. 21–23) gives a survey of the distribution of the categories of cnidae for most anthozoan genera. However, it must be remembered that some of the categories of nematocysts in this survey have been confused one with the other, and all will ultimately have to be reinterpreted.

Spirocysts, Bedot 1890

The spirocysts, because of their apparent differences from other nematocysts, have usually been considered a group apart from them. Weill (1934) devoted three short chapters to the spirocysts. He has chiefly summarized the older works on the spirocysts, adding very little new knowledge. As a result, our information on this group is little more than that given in the usual definition for it. Generally, the spirocysts are characterized as having affinity for acid dyes, and as having a thin, single-walled capsule and an unattached, solid, smooth, coiled thread which, when released from the capsule, unravels rather than evaginates. However, the examination of many spirocysts from many species brings to light discrepancies in the preceding definition. It is agreed that most spirocysts do have an affinity for acid dyes but at the same time there are some with a more or less neutral reaction to them. With respect to the structure of spirocysts I am in disagreement with almost all earlier interpretations except those of Will (1909) who is of the opinion that spirocysts are essentially the same as nematocysts.

The capsule walls of spirocysts exhibit every degree of thickness and refringence that can be found in the capsule walls of nematocysts. The development of the spirocysts in the cnidoblasts is, to my knowledge, much the same as for holotrichs, for example, and there is no reason to believe the capsule is single-walled in one case and double-walled in the other. Being a secreted structure the spirocyst is probably laid down in much the same way as the cuticular surface of certain epithelia. The capsule walls of spirocysts are usually very thin in actiniarians (Fig. 2, *a–e*) but generally thick in the corallimorpharians and ceriantharians (Fig. 2, *f–j*).

The distinction that the thread of the

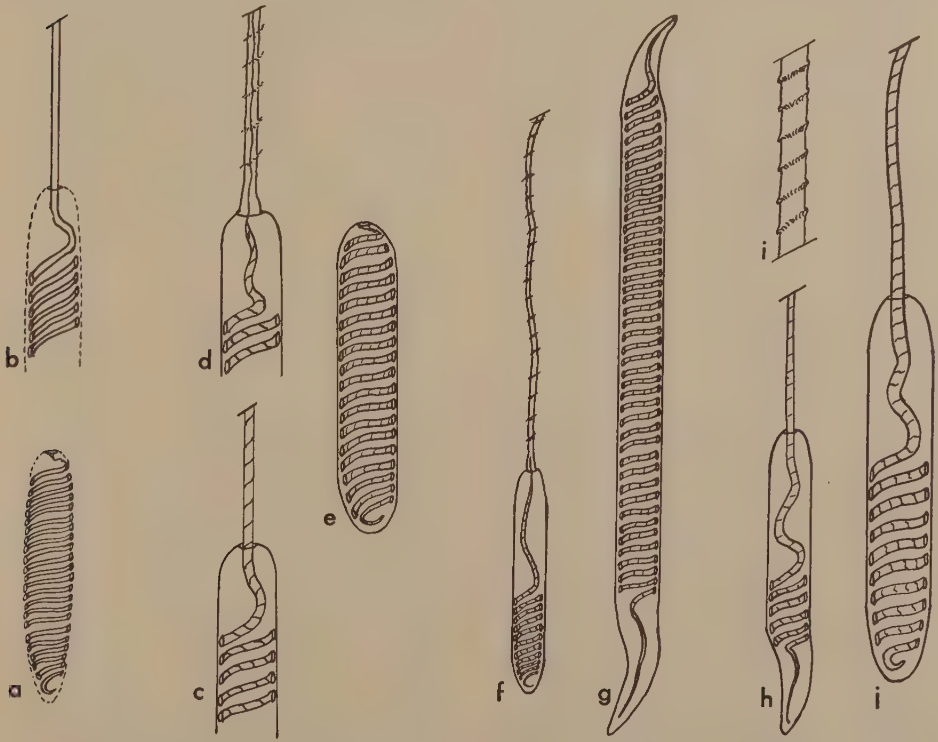

FIG. 2. Spirocysts. (*a,b*) *Aiptasia;* (*c–e*) *Boloceroides;* (*f,g*) *Corynactis;* (*h–j*) *Cerianthus;* (*i*) portion of invaginated tube, *Cerianthus.*

spirocyst is unattached and unravels is only partly true. When carefully made preparations are examined, the tubes of many spirocysts can be seen to be weakly attached to the capsules. This attachment is more readily observed when the preparations are from very young animals. In those spirocysts in which the tube is attached, the wall of the tube is considerably thinner at its juncture with the capsule wall and is usually deflated, wrinkled and twisted. When the tube remains attached there is enough purchase for the tube to evaginate precisely as it does in other nematocysts (Fig. 2, *d,f*). On the other hand, when the tube becomes detached, it unravels in an inverted condition (Fig. 2, *b,c,h,j*). The fact that the tube evaginates on occasion proves beyond doubt it is a tube and not a solid thread. In addition, drops of acid fuchsin in the lumens of both unraveled and evaginated tubes will occasionally traverse their lengths and spill out at the ends. The tubes of all spirocysts examined bore armature or evidence of armature. Very likely the reason other investigators have considered the tubes of spirocysts smooth is that the armature is sometimes fine, and because the tube only rarely evaginates, usually is found on the inside of the tube. However, the armature of most spirocyst tubes is no finer than that on the tube of the average holotrich, and with good resolution it can be discerned in either the unraveled or evaginated state. When the armature is on the inside of the tube it causes periodic, tangential ridges on the outer side of the tube.

Because the capsular contents of the spirocysts are quite uniform in structure, only the variability of the capsule size and shape and the distribution of the spirocysts in the species are of importance in systematics. Figure 2 illustrates a few shapes and sizes of spirocyst capsules. The spirocysts are probably restricted to the ectoderm, being most numerous in the tentacles and diminishing in number toward the mouth and pedal disc. Spirocysts rarely occur in the pedal disc, and some orders contain species which lack them in the column. Among the Anthozoa, spirocysts occur at least sparingly in all the orders except Octocorallia.

In light of these facts, the spirocysts, in all probability, represent a type of nematocyst whose main difference is its chemical nature.

Basitrichs, Weill 1930

The basitrichs are defined by Weill as those nematocysts which have a tube of the same diameter throughout its length and bearing armature on its proximal portion to an extent not exceeding three times the length of the capsule. However, if the characteristics given in the definition are rigidly adhered to, the nematocysts considered by Weill to be basitrichs do not qualify. Almost without exception Weill's basitrichs have a tube which is more rigid at the base, having thicker walls or a greater diameter in that region. All evidence indicates that the base of the tube is of greater caliber than the distal portion. It may be presumptuous to state that the man who defined almost the entire system of cnidae classification failed to recognize his own categories, but this appears to be the case. If Weill's basitrichs are retained as defined there remains a type of cnidae having a general distribution among the Anthozoa that he has failed to consider in its proper perspective. These nematocysts are characterized by having, in the undischarged condition, a completely or almost completely coiled tube which bears armature at the base. The fact that the tube is more or less completely coiled indicates that the proximal part has the same rigidity as the distal portion. This complete coiling results from the tube's being of uniform diameter and/or having walls of uniform thickness. Examples of this type of cnidae are illustrated in Figure 3. The complete coiling of the tube within the capsule and the small size of these nematocysts distinguish them from all others. Before deciding what to do with this category of nematocysts it would clarify the predicament if the next group to be considered (the microbasic *b*-mastigophores) were briefly previewed. The microbasic *b*-mastigophores are distinguished from the basitrichs by having a tube in which the caliber of the proximal part is slightly greater than that of the distal portion. Now, since there are two adequate categories extant (basitrichs and microbasic *b*-mastigophores) it appears that all that need be done is to restrict the types of nematocysts concerned to the existing definitions and terminologies that best fit them. In the case of the category, basitrichs, I propose to include only those nematocysts (Fig. 3, *a–i*) having completely coiled tubes (therefore of uniform diameter) in the undischarged state and bearing armature at least on their proximal portions. The capsules of these nematocysts rarely attain a length of 40μ.

Failure to recognize the category of nematocysts hereafter referred to as basitrichs has resulted in their being called sometimes atrichs and, at other times, microbasic *b*-mastigophores. For example, the Octocorallia are said to possess a solitary category of nematocysts, the atrichs. In reality the nematocysts of this order are basitrichs. Figure 9, *g,h,i* illustrates a basitrich from *Sarcothelia edmondsoni* Verrill. In addition to the confusion of basitrichs with atrichs, Carlgren has confused the basitrichs with microbasic *b*-mastigophores. He has stated repeatedly that to separate basitrichs from microbasic *b*'s it is necessary to observe them discharged. It is by this reasoning that the confusion exists, for it is next to impossible to determine (with an optical microscope) a difference in diameters of tubes when that difference may be 0.1μ or less. The measurements are further complicated by the diffusion effect of coarse armature at the base of the tube. As already mentioned the basitrichs (as redefined) are more readily distinguished from the microbasic *b*'s when undischarged. The tube of the basitrich is completely coiled in the capsule, whereas in the microbasic *b*'s the basal portion of the tube, because it has a greater diameter, is uncoiled. Some of the basitrichs (Fig. 3, *f*) show a tendency to intergrade with

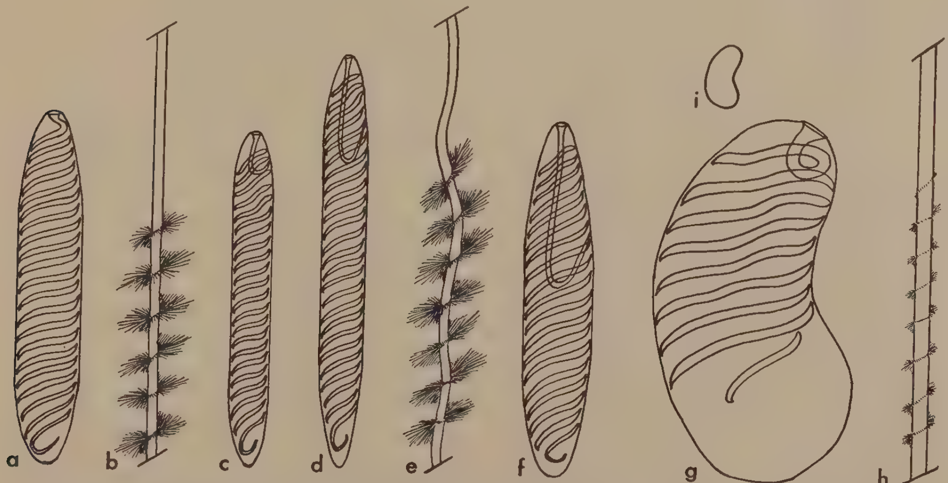

FIG. 3. Basitrichs. (*a,b*) *Anthopleura;* (*c*) *Bunodeopsis;* (*d,e*) *Aiptasia;* (*f*) *Fungia;* (*g–i*) *Sarcothelia;* (*i*) size of "*g*" drawn to scale of other nematocysts in figure.

the microbasic *b*-mastigophores but they are usually few in number and not critical to the diagnosis.

In distribution the basitrichs are more numerous in the tentacles, oral disc, and column. In the Actiniaria they are usually an inconspicuous category, being rare or absent in many genera. In the Octocorallia, on the other hand, they are numerous and the only category present.

Microbasic b-*mastigophores, Carlgren 1940*

The microbasic *b*-mastigophores of Carlgren are in part the microbasic mastigophores of Weill. By Weill's definition the tube of the microbasic mastigophore is differentiated into a proximal, armoured shaft less than three times the length of the capsule and a distal thread which may or may not be armoured (hoplotelic). However, Weill failed to notice that within this category there are nematocysts with two rather different shafts. One type has a shaft that tapers gradually to a thread, the other a shaft that narrows abruptly to a thread. Carlgren (1940) recognized the difference, and, to the type with a gradually tapering shaft he assigned the name, microbasic *b*-mastigophore. Those with abruptly tapering shafts he called microbasic *p*-mastigophores. In short, the microbasic *b*'s have been defined as having a capsular content consisting of an armoured shaft which is less than three times the capsule length and which tapers gradually to a thread that may or may not bear armature (be hoplotelic). Except for the hoplotelic condition of the thread, the definition is adequate for the category of nematocysts depicted in Figure 4. The threads of many nematocysts of this category are certainly hoplotelic. The question is, are the threads of all microbasic *b*'s hoplotelic? Among the microbasic *b*'s from many anthozoan genera examined there were only a few in which armature on the thread could not be resolved. Judging from the general tendency for the nematocysts of this category to be hoplotelic, it seems probable that with greater magnification and resolution they will all be found to have armoured threads. Un-

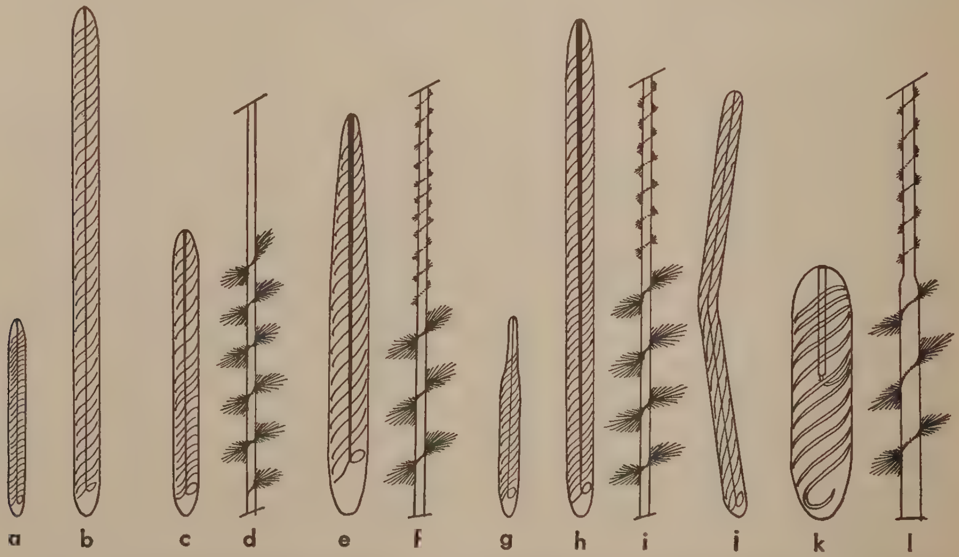

FIG. 4. Microbasic *b*-mastigophores. (*a,b*) *Phymactis;* (*c,d*) *Stoichactis;* (*e,f*) *Pocillopora;* (*g*) *Telmatactis;* (*h,i*) *Edwardsia;* (*j*) *Actiniogeton;* (*k,l*) *Fungia.*

til it can be proved whether or not the thread is always armoured it would seem more expedient for taxonomic purposes to assume all microbasic *b*'s are hoplotelic, or at least to minimize the importance of this feature in the diagnosis.

Like the basitrichs, the microbasic *b*'s are recognized more readily when undischarged. The shaft of the microbasic *b* is more rigid, as a consequence of its greater diameter, than the thread. For this reason the shaft occurs as a straight axial rod of variable length through the center of the capsule. Wherever the shaft may terminate within the capsule, the thread begins to coil around the shaft, against the capsule wall and back toward the capsule aperture.

The capsules of most microbasic *b*'s are quite uniform in shape. They are usually long, thin cylinders (sometimes exceeding 80μ in length), but occasionally are slightly pyriform (Fig. 4, *e*) or bottle-shaped (Fig. 4, *g*). A modification of these capsule shapes, heretofore overlooked, is a very long, thin, bent type which resembles a spicule or piece of straw. It is so thin the capsular content can scarcely be discerned within the capsule, and was never observed to evaginate. One of these nematocysts is illustrated in Figure 4, *j* but is somewhat thicker and shorter than most. They occur in the ectoderm of the column and pedal disc of certain species of Actiniaria. They are most numerous in the pedal disc and become rare toward the margin.

The microbasic *b*-mastigophores, like other categories of nematocysts, are only a segment of a continuous spectrum of nematocyst forms. There are a few microbasic *b*'s (Fig. 4, *k,l*) which intergrade with the microbasic *p*-mastigophores. To repeat, such intergrading forms are not critical in cnidae determinations.

The microbasic *b*-mastigophores seem to be most numerous in the Actiniaria, Zoantharia and Antipatharia; rare in Scleractinia, Corallimorpharia, and Ceriantharia; completely lacking in Octocorallia and Ptychodactiaria. The microbasic *b*'s occur in most organs of the animals but usually are most numerous in the tentacles, oral disc, and column. Sometimes they are lacking in organs that usually contain them, for example, the acontia of *Sagartiomorphe*.

Microbasic p-*mastigophores, Carlgren 1940*

The microbasic *p*-mastigophores of Carlgren are those microbasic mastigophores of Weill that have shafts which are abruptly reduced to threads. The shaft has a markedly greater diameter than the thread and, in the inverted condition within the capsule, is folded back within itself, thereby imparting to the folded end the appearance of a cone or V-shaped notch (Fig. 5). The shaft may vary in length from very short (Fig. 5, *b,c*) to three times the length of the capsule, the arbitrary limit for the category. If the undischarged shaft is the length of the capsule, it is almost always approximately twice the capsule length when discharged. The armature of the shaft is usually long and rather coarse,

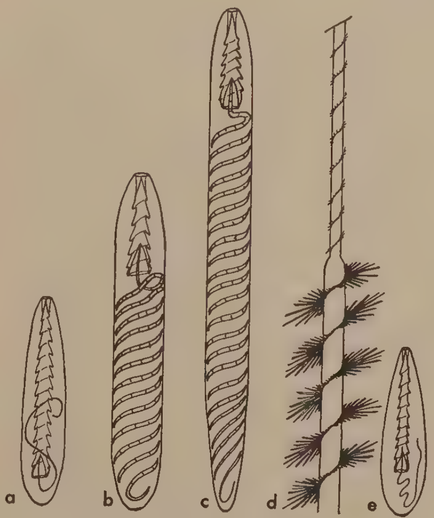

FIG. 5. Microbasic *p*-mastigophores. (*a*) *Anemonia;* (*b*) *Pocillopora;* (*c,d*) *Corynactis;* (*e*) *Cerianthus.*

the bristles sometimes clumping together and obscuring the three helically-coiled bands. The threads of the microbasic *p*'s, like the shafts, are of variable lengths (Fig. 5, *a–c*). Within the capsule the inverted thread, which is attached to the end of the shaft nearest the aperture, passes through the lumen of the shaft, and if the thread is long it coils behind the shaft. The fact that the thread is in the lumen of the shaft does not prohibit its evaginating before the shaft is completely expelled. According to Weill and Carlgren the threads of the nematocysts now called microbasic *p*'s are sometimes hoplotelic, sometimes not, and they have used this characteristic to subdivide the microbasic *p*'s. However, the microbasic *p*'s from numerous species of Anthozoa I have examined were all hoplotelic. The observations seem sufficient to indicate that the threads of all nematocysts of this category may bear armature, but because the presence of armature may sometimes be questionable it has little value in systematics.

Only the structure of the microbasic *p*-mastigophores of Carlgren has been considered. Before going further two other categories of nematocysts should be mentioned, the microbasic amastigophores of Weill and those nematocysts which have an additional discrete, unattached part associated with the capsular content. The latter group has heretofore been included with the microbasic *p*'s but in this paper will be considered a separate category to be described next in order. The amastigophores, according to Weill and Carlgren, have a capsular content consisting of a shaft only which is less than three times the length of the capsule. Carlgren (1945 and 1949) lists thirteen families of Actiniaria which supposedly possess microbasic amastigophores. Representatives of almost every genus of nine of these families were examined, and in every case a thread was found associated with the shaft. There are several reasons why the thread has been overlooked. The most peculiar situation is that of some "amastigophores" in *Bunodeopsis* (Fig. 6, *c,d*), similar kinds of which also occur in all other Boloceroididae. The capsular content consists of a typical shaft but the thread is short, very thin, and difficult to see. When the nematocyst is observed discharged, there is usually no thread at the end of the shaft. However, careful examination of the interior of the capsule reveals the thread to be adhering to the blind end of the capsule. After watching many of these nematocysts discharge it became quite evident that the thread sticks fast to the capsule wall. Before discharge of the capsular content the thread has a characteristic loop, and as the expulsion of the shaft begins the loop can be seen to draw taut. As evagination progresses the thread always (?) breaks from the shaft and the thread springs back just as it was before discharge. At present it is unexplainable why the thread is attached to the capsule of this type of nematocyst. The fact that the thread remaining in the capsule after discharge is the same length as before discharge is not necessarily inconsistent with the folded nature of the shaft described under general considerations of the cnidae. The thread of this particular type of microbasic *p* breaks at the folded end of the shaft (the notch) rather than the tip, probably due to constriction at this point, and the part within the shaft apparently is pinched so that in most cases it is not evaginated on discharge. The thread is so fine it cannot be readily discerned within the lumen of the shaft but on occasion part is evaginated with the shaft.

Microbasic *p*'s were also observed in several instances to have threads so nonrefractive as to be easily overlooked with ordinary illumination (Fig. 6, *f*). Threads of this type have considerable caliber (up to ¼ that of the shaft) but have walls so thin as to be transparent. The most common reason the threads are overlooked in those nematocysts that have been called amastigophores is that they are sometimes very short (Fig. 1, *e* and Fig. 6,

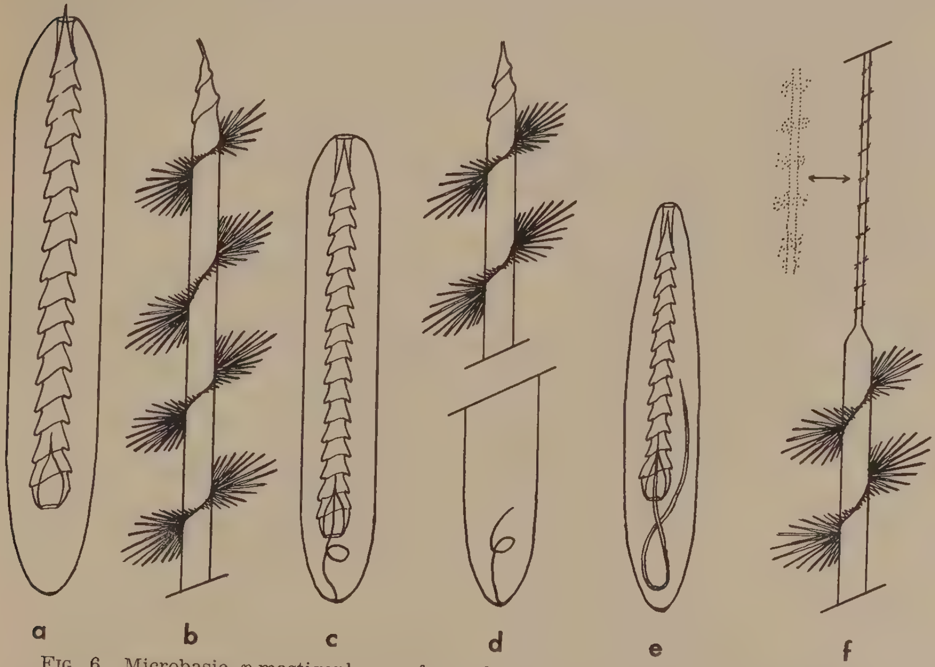

FIG. 6. Microbasic *p*-mastigophores, formerly called microbasic amastigophores. (*a,b*) *Actinothöe;* (*c*) *Bunodeopsis;* (*e,f*) *Macranthea;* (*d*) thread stuck to end of empty capsule and evaginated shaft without thread from same nematocyst, *Bunodeopsis.*

a,b). There must be some agreement as to the length of tube that constitutes a thread. If nematocysts with shafts tipped with a very short thread are to be considered distinctly different from those with long threads, then the former could conceivably be called amastigophores. However, this would be an arbitrary decision, there being neither a clear-cut morphological nor distributional distinction. There are certain genera, particularly in the Acontiaria, that characteristically possess microbasic *p*'s with vestigial threads in addition to those with distinct threads. But because these nematocysts with a short thread intergrade with the typical microbasic *p*'s and have a random distribution in the Anthozoa there is little to be gained by placing them in a separate category. It is therefore proposed to eliminate the category, microbasic amastigophore, and regard the nematocysts so designated as microbasic *p*-mastigophores.

The capsules of the microbasic *p*'s are almost always pyriform to elliptical in shape and their diameters are usually two or more times those of basitrichs or microbasic *b*'s of comparable length. The capsules vary greatly in size, some being less than 5μ, others exceeding 100μ.

Microbasic *p*-mastigophores occur most abundantly in the filaments, acontia, and actinopharynx but certain species lack them in one or more of these organs. Some species also possess them in the tentacles and column but there they are never as numerous as in the entodermal organs. The distribution of the microbasic *p*'s within the Anthozoa is rather uniform except for the orders Octocorallia and Ptychodactiaria where they are absent.

Microbasic q-*mastigophores* (*New Category*)

Iwanzoff (1896) was apparently the first to describe and figure the dart-like structure associated with the capsular content of certain mastigophores. He attributes the darts found in conjunction with these nematocysts from *Aiptasia diaphana* to the fusion of some of the armature shed from the nematocysts' tubes. Weill (1934) also is convinced that the dart represents part of the deciduous armature from the shaft which has become agglutinated. His Figures 122–125, p. 144, show several aspects of the dart from *Actinoloba* (= *Metridium*) *dianthus*. Two of the three darts shown in his Figure 123 are probably from two adjacent nematocysts and do not represent a case of several darts coming from a single capsule or a single dart becoming disassociated as he proposes. Iwanzoff and Weill consider the darts to be somewhat of an anomaly among nematocysts. The interpretations of both men are rather illogical, for it is difficult to conceive how the sloughed armature from the shafts of the nematocysts could become reorganized on every occasion to form the precise structure of the dart. It seems more reasonable to consider the dart an unattached, discrete structure consistently a part of the capsular content of certain kinds of nematocysts. Figure 7, *a–d* represents diverse aspects of the darts from the acontia of *Aiptasia pulchella*. The dart (Fig. 7, *a*) is discernible within the lumen of the undischarged shaft where it neatly fits over the end of the folded part of the shaft. On discharge of the nematocyst the dart is ejected and pushed aside by the evaginating tube. Once free of the capsule the fine, transverse striations (probably armature) are visible on the dart (Fig. 7, *d*). In addition to the observations on the dart, the fact that the tubes of the discharged nematocysts retain their armature rather conclusively discounts the theory of the dart's being formed from sloughed armature. Further, the presence of the thread on the discharged shaft rules out an alternative hypothesis that the dart is a portion of the shaft. Although the derivation of the dart is unknown at present, there can be little doubt the dart is a real and innate structure peculiar to certain microbasic mastigophores. Therefore, it is proposed to call those nematocysts with a shaft less than three times the length of the capsule and abruptly reducing to a thread, and with a detachable dart on the end of the invaginated shaft, microbasic *q*-mastigophores.

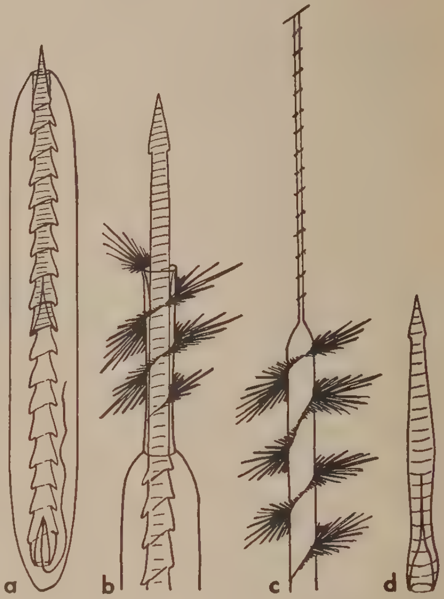

FIG. 7. Microbasic *q*-mastigophores from *Aiptasia*. (*a*) undischarged nematocyst; (*b*) beginning of evagination; (*c*) shaft of same nematocyst with thread; (*d*) dart from same nematocyst.

The survey of microbasic *q*-mastigophores is extremely incomplete. In the few species of actinians found to possess microbasic *q*'s, the nematocysts seem to be restricted to the acontia. At the present time microbasic *q*'s are known to occur in only four species of *Aiptasia* and one species of *Metridium*, but now that these nematocysts have been redescribed in a new light many species of actinians, particularly Acontiaria, are likely to be found to have them.

Macrobasic p-*mastigophores* (*New Category*)

In the category, macrobasic *p*-mastigophores, it is proposed to include those nematocysts with a shaft which is more than three times the length of the capsule and which is abruptly reduced to a thread. The shaft in the undischarged condition is invaginated and folded back within itself. The armature of the shaft is distinctly longer than that of the thread. The shaft may have a diameter only slightly greater than the thread, causing the juncture of the shaft and thread to be obscure. This definition includes the macrobasic amastigophores (Fig. 8, *a,b*) and some holotrichs (Fig. 8, *c–g*) of Weill and Carlgren.

Macrobasic amastigophores were examined from all actiniarian families reported to possess them and were found to have threads. Although the threads are very short (e.g., Fig. 1, *e*), their presence distinguishes these nematocysts as *p*-mastigophores, and because the shafts are more than three times the length of the capsule, a new category, macrobasic *p*-mastigophores, is erected for them. The shafts of these nematocysts are of variable length and within the capsule may correspondingly form one to several longitudinal coils. The nematocysts are refractory to stain and the tube evaginates reluctantly. Carlgren (1940 and 1949) attributes macrobasic amastigophores to only the actiniarian families Aliciidae and Diadumenidae. However, I have found this type of nematocyst (now referred to as macrobasic *p*'s) in the Boloceroididae (Fig. 8, *a*) and rarely in the Aiptasiidae. Upon closer inspection they will likely be found in other families of Actiniaria. The macrobasic *p*'s occur in the ectoderm of the column, where they usually are restricted to the vesicles, but in the Diadu-

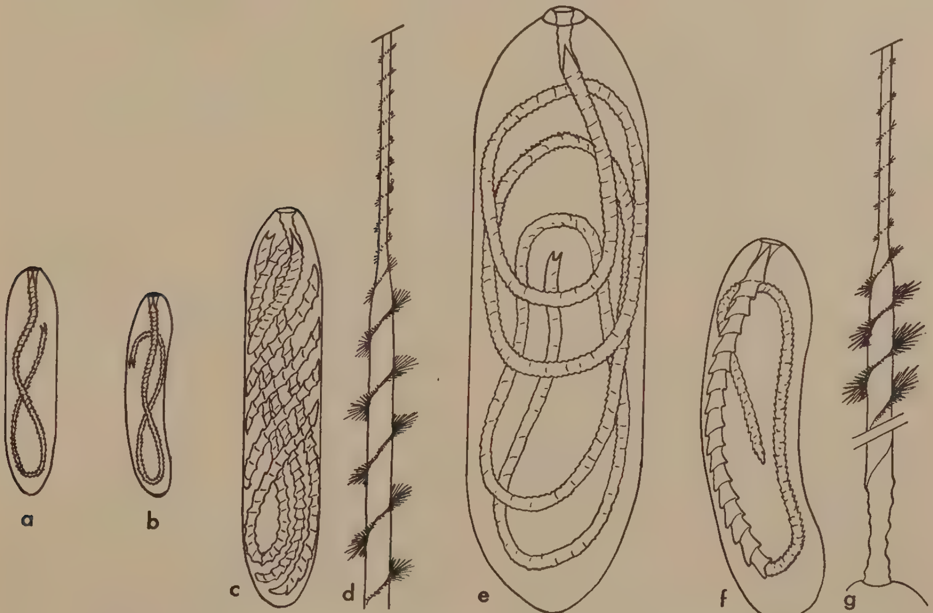

FIG. 8. Macrobasic *p*-mastigophores. (*a*) *Bunodeopsis;* (*b*) *Alicia;* (*c,d*) *Corynactis;* (*e*) *Rhodactis;* (*f,g*) *Cerianthus.*

menidae they are found in the ectoderm of the tentacles (catch tentacles excepted). The rarity of this type of nematocyst, its spotty distribution in the Anthozoa, its short thread, and its reluctance to evaginate suggest it may be a relic in the Actiniaria.

In addition to the macrobasic *p*-mastigophores just described, there are certain large nematocysts (Fig. 8, *c–g*) found in the Corallimorpharia and Ceriantharia which have heretofore been called holotrichs but, unlike holotrichs, have a tube that is divisible into a shaft and thread. The reason they have been considered holotrichs may be that the tube is usually very long and the slight demarcation between shaft and thread is overlooked. The shaft may be 4 to 30 times the length of the capsule and be reduced to a thread which is sometimes more than two-thirds the diameter of the shaft. Similar nematocysts with a shaft 4 to 6 times the length of the capsule (Fig. 8, *f,g*) have been consistently called hoplotelic microbasic *b*-mastigophores by Weill and Carlgren. Unlike microbasic *b*'s which sometimes have a distinctly differentiated shaft (Fig. 4, *k,l*) but which are simply invaginated within the capsule, these nematocysts (Fig. 8, *f,g*) have a shaft that is invaginated and folded within itself. They therefore resemble *p*-mastigophores and not *b*-mastigophores. There is frequently present a rather long tube (the proximal portion of the shaft) (Fig. 8, *e*) between the capsule aperture and the point of the shaft. This arrangement of the capsular content and the V-shaped notch at the folded end of the tube is identical to the configuration of the undischarged contents of *p*-mastigophores. Because this nematocyst has a shaft more than three times the length of the capsule and folded within itself, it is referred to the category, macrobasic *p*-mastigophores.

The armature of the shaft of large macrobasic *p*'s is never as long and coarse as that on the shafts of other *p*-mastigophores but it is usually about twice as long as the armature on the thread. The tube of these large macrobasic *p*'s is apparently thin-walled, for when it evaginates it becomes considerably inflated, causing it to lengthen and sometimes attain a diameter of 15μ or more near the base. Such distension causes the bands of armature to become separated and the tube to appear rather bare. Frequently the shaft is unarmoured proximally for as much as two-thirds of its length. In addition, the armature seems to be deciduous and when it is lost the tube appears like that of an atrich. It is possible some of the very large atrichs described from cerianthids and corallimorpharians are macrobasic *p*'s which have lost their armature. The thread of the large macrobasic *p*'s is usually approximately the length of the shaft. Being thin-walled it is inflated when evaginated and in spite of its considerable diameter is difficult to discern.

The large macrobasic *p*-mastigophores are a major element of the cnidoms of Ceriantharia and Corallimorpharia. They occur in all nematocyst-bearing organs and in either the ectoderm or entoderm.

The group of nematocysts comprising the category, macrobasic *p*-mastigophores, may seem heterogeneous because the nematocysts vary in size and have different distributions. However, the nematocysts of the group are very similar structurally. The large nematocysts of the category form an element of the anthozoan cnidom which is well represented in the seemingly more ancient Ceriantharia and Corallimorpharia. Their smaller counterpart, on the other hand, may represent a rare relic in the apparently more recent order Actiniaria.

Holotrichs, Weill 1930

The holotrichs are those nematocysts with a tube of uniform diameter which is uniformly armoured throughout its length. They are typically long, thin capsules with a neat and completely coiled content (Fig. 9, *a–d*). They sometimes have very fine armature on the tube which, if overlooked, results in confusion of these nematocysts with atrichs. Usually the long, thin nematocysts of the marginal spherules (acrorhagia) are described as atrichs. All marginal spherules I have examined contained holotrichs but no atrichs. Likewise, the nematocysts in the tentacles of the *Sagartiomorphe* (Fig. 9, *d*), which Carlgren (1949) mistakenly calls atrichs, are holotrichs. The long, thin holotrichs seem to be a product of the ectoderm. They occur chiefly in the marginal spherules and tentacles and rarely in the column of actiniarians. It is doubtful if they occur in other orders of Anthozoa.

The assemblage of nematocysts called holotrichs is heterogeneous, the category probably being a catch-all for several types which we are at present unable to separate satisfactorily. In the discussion of the preceding category I have shown that some are macrobasic *p*-mastigophores. However, there remains at least one type to be considered. These nematocysts (Fig. 9, *e–i*) are the very large, broad ones found in the Ceriantharia, Corallimorpharia, Zoantharia and young forms of certain Actiniaria. Although this type of nematocyst has a tube like that of a holotrich, it is different in other respects. This nematocyst has a different distribution, it is broader and larger, the coiling of the tube is loose and irregular, it is refractory to stains, and evaginates differently. A clue to the identity of this nematocyst may be gained from an investigation of cnidogenesis in the Anthozoa. Although the data on cnidogenesis are very incomplete, large nematocysts resembling Figure 9, *f* have been found in the larvae and young of several species of Actiniaria. These nematocysts are always a very short-termed element of the species' cnidoms and have never been found in the adults. These observations suggest that the large holotrichs (?) may be a generalized prototype of all other nematocysts. However, the evidence seems insufficient to warrant the erection of a new category for them; thus (with reservations) I prefer to retain them in the holotrich category.

The large holotrichs (Fig. 9, *e–i*) are found in both the ectoderm and entoderm of Ceriantharia, Corallimorpharia, Zoantharia, and Scleractinia and are present in almost all the nematocyst-bearing organs.

Atrichs, Weill 1930

The atrichs are defined as nematocysts with an unarmoured tube of uniform di-

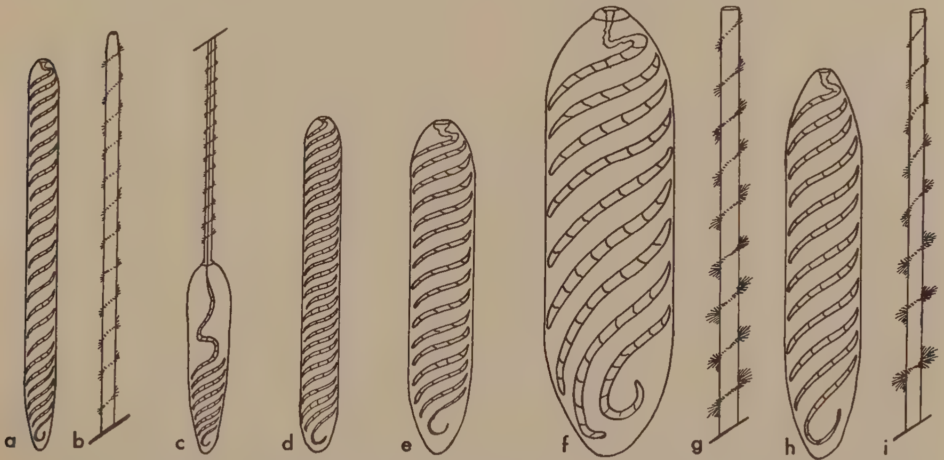

FIG. 9. Holotrichs. (*a,b*) *Anthopleura;* (*c*) *Diadumene;* (*d*) *Sagartiomorphe;* (*e*) *Cerianthus;* (*f,g*) *Zoanthus;* (*h,i*) *Fungia;* (*b,g,i*) tips of evaginated tubes.

ameter. The atrich category, like that of the holotrichs, seems to be comprised of two types, a small variety found only in the Actiniaria and a larger variety found in the Ceriantharia, Corallimorpharia, and Zoantharia.

The small atrichs (Fig. 10, *a,b*) are broad nematocysts with a very long tube which is coiled somewhat elongately in the capsule. They take up methylene blue, and the tube evaginates readily. The small atrichs are known only from the ectoderm of catch-tentacles of species of the family Diadumenidae. Atrichs described for other Actiniaria have proved to be either basitrichs or holotrichs and are discussed under these categories.

The large atrichs (Fig. 10, *c,d*) differ from the small ones in the following respects. They are frequently more than twice the length of the small ones but in proportion are not so broad. The tube is more transversely coiled in the capsule and evaginates with reluctance. The nematocysts are refractory to methylene blue and acid fuchsin. They occur in the ectoderm and entoderm of most nematocyst-bearing organs of Ceriantharia, Corallimorpharia, and Zoantharia.

The tubes of the large atrichs evaginate so rarely that few details of the tube are known. On several occasions what appeared to be fine, sloughed armature was found in conjunction with crushed nematocysts resembling large atrichs. An investigation of the development of these nematocysts might indicate possible relationships with other types. However, until we have more data on these nematocysts it seems best to consider them atrichs.

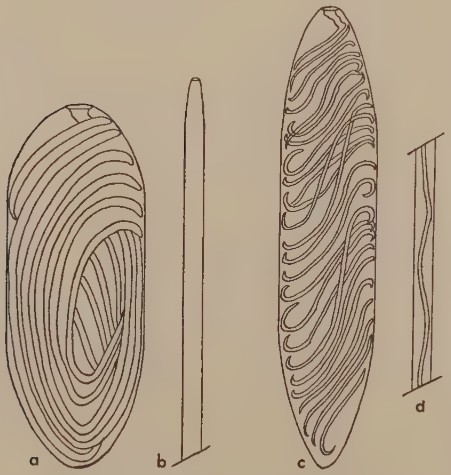

FIG. 10. Atrichs. (*a*) *Diadumene;* (*b*) tip of evaginated tube, *Diadumene;* (*c*) *Cerianthus;* (*d*) portion of invaginated tube in lumen of evaginated tube, *Cerianthus.*

Summary and Conclusions

The enduring and varied features of nematocysts make them an excellent potential index to the phylogeny of the Coelenterata. Through the efforts of Robert Weill and Oskar Carlgren the nematocysts of the Coelenterata have been classified and demonstrated to be of systematic value. However, when species for which one or the other of these men had determined cnidoms were examined, the nematocysts were frequently found to be different than reported. The incongruity of my observations with theirs led to the belief that some types of nematocysts had been misinterpreted for one or more reasons. The principal difference of interpretation proved to be of the finer structures of the nematocysts, e.g., the armature on the thread, or the configuration of the contents of the capsules. The discernment of such features is frequently contingent on the quality of the microscope, the magnification, and the investigator's visual acuity. A survey was made of representatives of all but one order (Ptychodactiaria) of Anthozoa to establish criteria for the recognition of nematocysts of the class which would be less dependent on these variables.

On the basis of the survey two new categories (microbasic *q*-mastigophores and macrobasic *p*-mastigophores) are proposed. Two categories (micro- and macrobasic amastigophores) are eliminated. The reappraised and new categories are:

1. Spirocysts. Acidophilic nematocysts with a tube of uniform diameter which bears armature of uniform length throughout.

2. Basitrichs. Nematocysts with a tube of uniform diameter which bears coarse armature proximally for a distance less than three times the capsule length.

3. Microbasic *b*-mastigophores. Nematocysts with a proximal shaft which is less than three times the capsule length and which is indistinctly reduced to a distal thread. There is armature on the shaft which is distinctly longer than that on the thread.

4. Microbasic *p*-mastigophores. Nematocysts with a proximal shaft less than three times the capsule length and abruptly reduced to a distal thread. The armature of the shaft is distinctly longer than that of the thread. The undischarged shaft is invaginated and folded back within itself.

5. Microbasic *q*-mastigophores. Nematocysts with a proximal shaft which is less than three times the capsule length, which is abruptly reduced to a distal thread, and which bears armature distinctly longer than that of the thread. The shaft is doubly invaginated within the capsule and has an unattached dart over its tip.

6. Macrobasic *p*-mastigophores. Nematocysts with a proximal shaft which is more than three times the capsule length, which is abruptly reduced to a thread, and which has armature distinctly longer than that of the thread. The shaft within the capsule is doubly invaginated.

7. Holotrichs. Basophilic nematocysts with a tube of uniform diameter bearing armature of uniform length throughout.

8. Atrichs. Nematocysts with a smooth tube of uniform diameter.

The macrobasic *p*-mastigophores and holotrichs each seem to be heterogeneous assemblages of nematocysts, but there is insufficient evidence to segregate them into more homogeneous categories.

The effect of alterations in the categories of cnidae on anthozoan systematics must be further evaluated. It is unlikely that radical changes in the phylogenetic arrangement of the members of the class would be necessary, for nematocysts are far from being the only criterion upon which anthozoan systematics is based. It is hoped that a more immediate consequence of the re-interpretation of the cnidae will be a simplified and more consistent identification of types of nematocysts.

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A Revision of the Surgeon Fish Genus *Acanthurus*[1]

JOHN E. RANDALL

THIS IS THE FOURTH in a series of papers dealing with the surgeon fishes (family Acanthuridae). An analysis of the genera and revisions of *Zebrasoma*, *Paracanthurus*, and *Ctenochaetus* have been published (Randall, 1955*a*, *b*, *c*). *Acanthurus*, with 32 species (one of which is described as new), is treated in the present paper, the first to consider all of the species of this circumtropical genus since the review by Günther in 1861.

The work has been based primarily on the collections of surgeon fishes in the following institutions: United States National Museum, Stanford Natural History Museum, California Academy of Sciences, Museum of Comparative Zoology at Harvard College, Bernice P. Bishop Museum, Academy of Natural Sciences of Philadelphia, University of Hawaii, University of Miami, University of California at Los Angeles, and the Pacific Oceanic Fishery Investigations, Honolulu.

I acknowledge with gratitude the assistance and guidance of William A. Gosline of the University of Hawaii and Leonard P. Schultz, Ernest A. Lachner, Robert H. Kanazawa, and Frederick M. Bayer of the United States National Museum.

Special thanks are due Boyd W. Walker of the University of California at Los Angeles, George S. Myers and Robert R. Harry of Stanford University, Joseph E. King of the Pacific Oceanic Fishery Investigations, and J. L. B. Smith of Rhodes University College, South Africa for information and loan of specimens.

I am grateful to L. Bertin of the Museum National d'Histoire Naturelle at Paris; W. Klausewitz of the Senckenberg Museum at Frankfurt, N. B. Marshall and especially Alwyne C. Wheeler of the British Museum of Natural History who have been most cooperative in supplying information on type specimens.

I am most appreciative of the assistance and advice of the research laboratories of the Eastman Kodak Company on the colored plates and for the printing of Plate 2.

E. J. Brill of Leiden, Netherlands, have kindly permitted the use of the figure of *Acanthurus leucosternon* published as Figure 26 of Volume IX of *Fishes of the Indo-Australian Archipelago* by L. F. deBeaufort and W. M. Chapman.

Most of the species of *Acanthurus* are wide-ranging and have been described many times under different names. A total of 110 Recent specific names, discounting misspellings, have been proposed for *Acanthurus* and its synonyms, and seven names from other surgeon fish genera have been applied to species of the genus.

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[1] A portion of a thesis submitted to the Department of Zoology, University of Hawaii, in partial fulfillment of the requirements for the degree of Doctor of Philosophy. Contribution No. 75, Hawaii Marine Laboratory in cooperation with the Department of Zoology and Entomology, University of Hawaii. Manuscript received April 20, 1955.

In the preparation of the synonymy for each species, mere listings or names with insufficient descriptive data have been omitted generally unless I have seen the specimens reported. References in the synonymy are given with no locality when an author did not cite the locality or when he based his record on the work of a previous author. Misidentifications are indicated by a period immediately following the specific name.

The original descriptions of a few species for which there are no known types are so fragmentary (or in cases probably erroneous) that it would be pure guess work to allocate the names to known forms. In this category are the following: *Acanthurus Militaris* Shaw, *Acanthurus Umbratus* Shaw, *Acanthurus Meleagris* Shaw, *Acanthurus fuliginosus* Lesson, *Acanthurus fraterculus* Cuvier and Valenciennes, and *Acanthurus lineolatus* Cuvier and Valenciennes.

The only species of *Acanthurus* described by Shaw (1803) which has been recognized is *A. achilles*. I have never seen other Shaw names used, and the descriptions are much too brief to permit identifications. A. C. Wheeler of the British Museum answered my query about types by writing, "I have searched everywhere for Shaw's types, and I am quite certain that they are now not in existence, be they in spirit, stuffed, or skins."

Acanthurus fuliginosus was figured by Lesson (1830: pl. 27, fig. 2) as a uniformly brown fish with a broad bright blue line under the chin. In life there were fine, transverse, reddish lines on the body. I know of no species with such coloration. Certainly the use of the name by Fowler, Schultz, and others for *Acanthurus xanthopterus* Cuvier and Valenciennes is not proper, as has been pointed out by de Beaufort (1951: 159).

Acanthurus fraterculus Cuvier and Valenciennes was described from a figure by Renard as brown with three oblique blue and red bands on each side of the head, a blue spot below the middle of the dorsal fin, and green fins except the spinous dorsal which is blue and yellow. Although Günther (1861: 341) listed this species, he added that it had not been recognized.

Chaetodon elongatus Lacépède (1803: 454) is a special problem. It is a species of *Acanthurus*, and the type (No. A. 2506) is in the Paris Museum. L. Bertin (personal communication) writes that it is 90 mm. in standard length, has 16 upper teeth, and a caudal concavity of 4 mm. He adds that the specimen is dry, in very poor condition, and with no color markings perceptible. Günther (1861) listed *A. elongatus* as a questioned synonym of *Acanthurus nigrofuscus* (Forskål); the most frequent use of the name *elongatus* has been for *A. nigrofuscus;* however *A. elongatus* could not be this species. A 90 mm. specimen of *A. nigrofuscus* would have, at most, 12 upper teeth and would have a caudal concavity of about 16 mm. *Acanthurus elongatus* is probably a subadult of one of the larger species of *Acanthurus* such as *A. dussumieri* Cuvier and Valenciennes, *A. xanthopterus* Cuvier and Valenciennes, or *A. mata* (Cuvier). It is difficult to identify even fresh specimens of 90 mm. length of species in this complex. Because of the apparent juvenile nature and poor state of preservation of the type specimen, coupled with the inadequate original description, *elongatus* should be considered a *nomen inquirendum*.

Acanthurus rackliffei Schultz (1943: 157, 163, fig. 13) is probably a hybrid of *Acanthurus achilles* Shaw and *Acanthurus glaucopareius* Cuvier (Randall, in press, *d*).

Sauvage (1891: 519) listed *lunulatus* Liénard among the species of *Acanthurus* from Madagascar. I am unable to find the work of Liénard in which this species was described. This author was at times nonbinominial.

Acanthurus doreensis Cuvier and Valenciennes is here treated as a doubtful species.

Some species of *Acanthurus* have been described from the late postlarval or acronurus stage, and many of these were originally placed in the genus *Acronurus* Gronow. The larval nature of *Acronurus* has been known at least since Günther (1873); nevertheless as recently as 1944 Fowler described a new species in the genus. It has not been possible in most cases for me to determine the correct adult name for species described from acronurus or early juvenile stages. The following such species I cannot place, with assurance, in synonymy: *Acronurus orbicularis* Quoy and Gaimard, *Acronurus fuscus* Gronow, *Acronurus anginosus* Bleeker, *Acronurus brevispinis* Günther, *Acronurus argenteus* Günther (not of Quoy and Gaimard), *Acronurus melanurus* Day, *Acronurus carneus* Poey, *Acronurus lineolatus* Klunzinger, *Acronurus machaeropterus* Fowler, *Acanthurus melanurus* Cuvier and Valenciennes, *Acanthurus melas* Cuvier and Valenciennes, *Hepatus leucopareius* Fowler (from Guam), *Teuthis elongatus* Kendall and Goldsborough, *Hepatus elegans* Kamohara (not of Garman), and *Teuthis spinifrons* Whitley.

I have been more successful in identifying to species actual museum specimens of acronurus forms and early juveniles. Some of these are shown in Figure 1. The adults of all of the species of *Acanthurus* are figured.

I have seen specimens of all of the known species of *Acanthurus* except *A. polyzona* (Bleeker), *A. leucocheilus* Herre, and *A. mindorensis* Herre. A. W. Herre has informed me that the types of the latter two were destroyed at Manila. To my knowledge there are no other specimens in existence. The specimens which Herre (1934: 62) identified as *A. leucocheilos* [*us*] are *Acanthurus pyroferus*.

Like most fishes, there are some obvious differences with age in species of *Acanthurus*. With increasing age, the eye becomes relatively smaller, the caudal fin generally more lunate, and in many species the body is more elongate; the teeth increase in number and at least in some species (see Table 16 under *A. gahhm*) the number of denticulations on the teeth decrease (for this reason the lengths are given for specimens from which teeth are taken for the tooth drawings of Fig. 2). Most striking in many species are the color changes with age. Examples are as follows: the young of *A. coeruleus* Bloch and Schneider and *A. olivaceus* Bloch and Schneider are solid yellow in color; the distinctive mark found on the shoulder region of many of the species of *Acanthurus* is not present in juveniles; the semicircular black shoulder mark of *A. tennenti* Günther changes in older individuals to two elongate black bands; *A. achilles* does not develop its bright orange spot on the caudal peduncle until it has attained a size of about 65 to 70 mm.

Two keys are given, one to the Indo-Pacific species and one to the Atlantic species, not because there are any marked differences between the species of these two major regions, but as a convenience to the reader. The species are keyed out, insofar as possible, in natural groups (as based on superficial characters). These species groups are not sufficiently demarked from one another, in my opinion, to be regarded as subgenera. They are as follows:

1. *A. triostegus* (Linnaeus) and *A. polyzona* (Bleeker).
2. *A. nubilus* (Fowler and Bean), *A. bleekeri* Günther, and *A. thompsoni* (Fowler).
3. *A. nigrofuscus* (Forskål), *A. nigroris* Cuvier and Valenciennes, *A. leucopareius* (Jenkins), *A. guttatus* Bloch and Schneider, and possibly *A. coeruleus* Bloch and Schneider.
4. *A. lineatus* (Linnaeus) and *A. sohal* (Forskål).
5. *A. achilles* Shaw, *A. glaucopareius* Cuvier, and *A. leucosternon* Bennett.
6. *A. pyroferus* Kittlitz.
7. The remaining three Atlantic species and the last 11 Indo-Pacific species (*A. leucocheilus* and *A. mindorensis* not considered).

A. pyroferus is placed by itself because of its intermediacy between Groups 5 and 7; this is discussed in detail under *A. pyroferus*.

Group 7 constitutes a superspecific assemblage which has as its most characteristic feature a large, round, thick-walled stomach. Such a gizzard-like stomach is not found in any other *Acanthurus* except *A. pyroferus*. These species are commonly found in bay or lagoon environments, and the gut contents generally contain a large percentage of hard, coarse, sedimentary material. The teeth tend to be elongate with numerous denticulations. Eight of the Indo-Pacific species develop with age a distinctive color mark in the shoulder region just above the gill opening. In most of the species the caudal spine is accentuated by being surrounded with color (often black or dark brown). They are not exclusive in this feature, however, for *Acanthurus achilles*, *Acanthurus sohal*, and certain species of *Naso* have their caudal spines contained within areas of bright color. Presumably this color serves as warning coloration, a means of calling attention to the sharp caudal spines. There is a tendency in this group toward large size, this being most apparent in *A. xanthopterus*, *A. dussumieri*, and *A. mata*.

TABLE 1
DISTRIBUTION OF THE SPECIES OF *Acanthurus*

MAJOR TROPICAL AND SUBTROPICAL REGIONS	NO. OF SPECIES KNOWN TO OCCUR IN REGION	NO. OF SPECIES CONFINED TO REGION
Indo-Pacific (28 species)		
Indian Ocean	13*	3†
Common to Indian Ocean and Indo-Malaya	12	2
Indo-Malayan region‡	23	6
Common to Indo-Malaya and Oceania	15	5
Oceania§	17	2
Common to Indian Ocean and Oceania	10	8
Eastern Pacific	3	0
Atlantic (4 species‖)		
Western Atlantic	3	2
West Africa	2	1

* *Acanthurus glaucopareius* is recorded from Christmas Island and Cocos-Keeling Islands in the Indian Ocean. Since these are near the East Indies and the species is unknown from the rest of the Indian Ocean, it is not included in this figure.

† Includes *Acanthurus sohal*, a species known only from the Red Sea.

‡ East Indies, northern Australia, Malaya, and Philippine Islands.

§ Oceanic islands of the tropical western, southern, and central Pacific Ocean.

‖ The Indo-Pacific *Acanthurus triostegus* is not included in this figure, although there is one record of this species from West Africa.

It is only in this last group of species that I have observed sexual dimorphism in *Acanthurus*. Large adult males develop a definite convexity in the profile of the head above the mouth. Although there is a tendency for the profile to become more convex regardless of sex, it is much more evident in males than in females of the same size.

DISTRIBUTION

The distribution of the species of *Acanthurus* as indicated in the keys and Table 1 is based on localities of museum specimens seen by me and records from the literature about which there is little or no question. Further collecting may result in the extension of the range of some of the species.

Like most widely-distributed genera of tropical marine fishes, the greatest number of species of *Acanthurus* occurs in the Indo-Malayan region.[2] Twenty-three are recorded from the East Indies and Philippines, six of which are endemic to the area. This is a higher degree of endemism than that of any other region.

Only two species of *Acanthurus*, *A. achilles* and *A. leucopareius*, appear to be confined to oceanic islands of the Pacific. The latter is known by authentic records only from the Hawaiian Islands, Marcus Island, and Easter Island, areas widely separated and peripheral in Oceania, suggesting that *A. leucopareius* may be a relict species.

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[2] The surgeon fish genera *Zebrasoma* and *Ctenochaetus*, however, do not follow this pattern. Of the six species of *Zebrasoma*, none are endemic to the Indo-Malayan region; two are confined to the Indian Ocean and two to the Pacific. Although two of the seven species of *Ctenochaetus* are restricted to the East Indies and Philippines, three are known only from islands in the central and eastern Pacific.

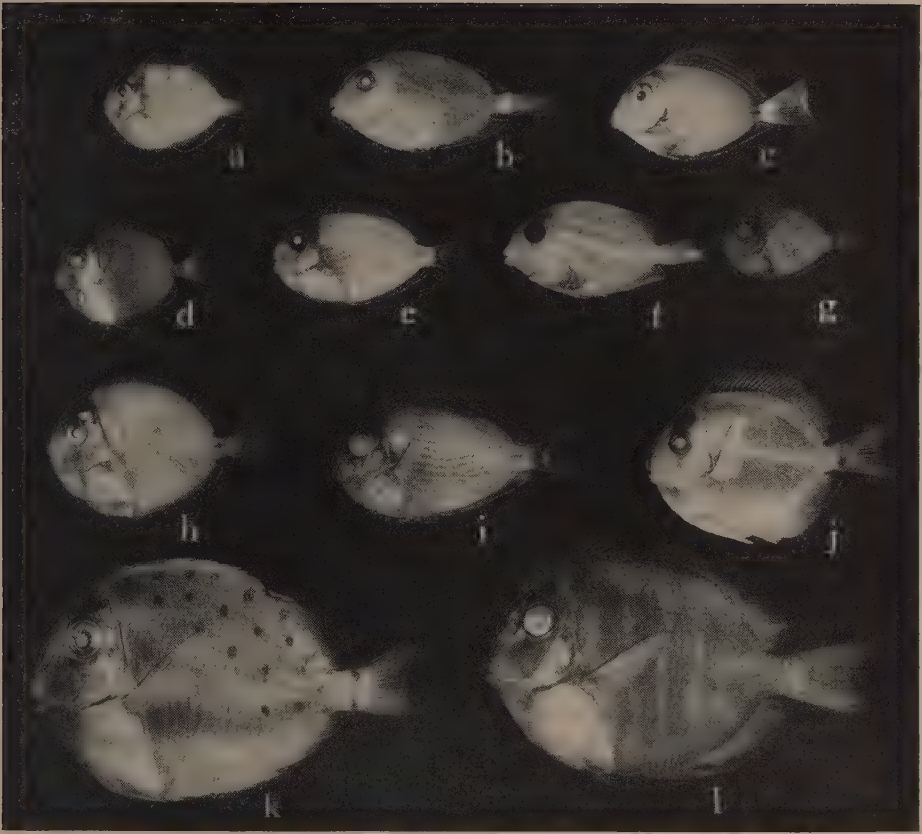

FIG. 1. Acronurus and very young juvenile stages (as indicated) of species of *Acanthurus: a, triostegus triostegus*, Guam, U.S.N.M. No. 139750; *b, chirurgus*, Puerto Rico, U.S.N.M. No. 73825, (juvenile); *c, bahianus*, Puerto Rico, U.S.N.M. No. 147648, (juvenile); *d, mata*, Oahu, Hawaiian Islands, U.S.N.M. No. 167248; *e, lineatus*, Mariana Islands, U.S.N.M. No. 139759; *f, olivaceus*, Eniwetok, Marshall Islands, U.S.N.M. No. 139998, (juvenile); *g, sohal*, Jidda, Red Sea, U.S.N.M. No. 147552; *h, dussumieri*, Oahu, Hawaiian Islands, U.S.N.M. No. 167247; *i, nigroris*, Wake Island, U.S.N.M. No. 167249; *j, guttatus*, Tau, Phoenix Islands, U.S.N.M. No. 115134; *k, achilles*, Oahu, Hawaiian Islands, U.S.N.M. No. 150744; *l, glaucopareius*, Kwajalein, Marshall Islands, U.S.N.M. No. 139955.

Acanthurus lineatus, though widely distributed, is not reported from the Red Sea. The species which most resembles *A. lineatus* is *A. sohal*. The latter appears to be restricted to the Red Sea. *A. achilles* and the similar *A. leucosternon* are not recorded from the same area; *A. achilles*, as mentioned, seems to be characteristic of Oceania whereas *A. leucosternon* is an Indian Ocean and East Indian species. The Indian Ocean species *A. tennenti* is very closely related to *A. olivaceus*. The latter, however, does not seem to occur in the Indian Ocean, but ranges from the East Indies into the tropical Pacific. Although further collecting may result in the two species of these three pairs being found together, it may be

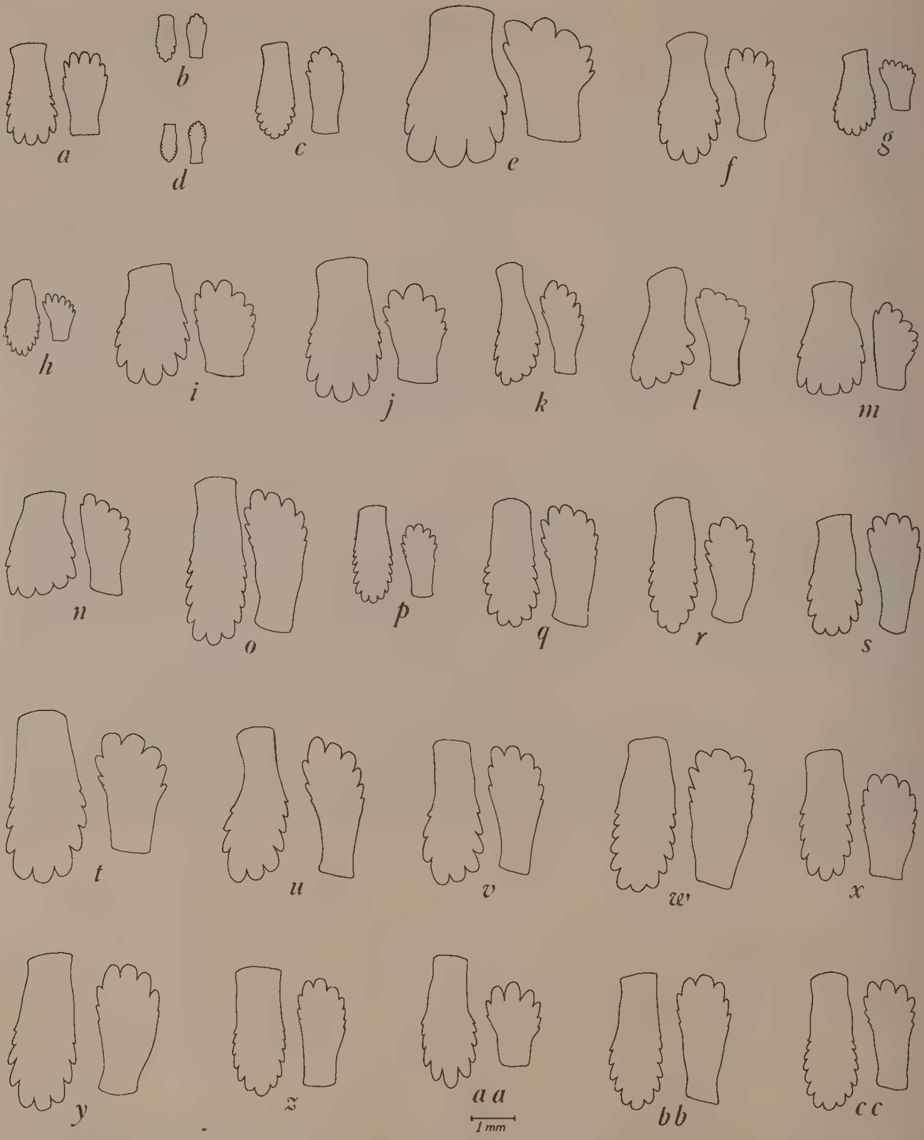

FIG. 2. Camera lucida drawings of upper (left) and lower (right) teeth of various species of *Acanthurus*. Teeth were taken from right side of jaws near center and drawn in inner or lingual view. *a*, *triostegus*, 140 mm. specimen, Marshall Islands; *b*, *nubilus*, 156 mm. specimen, East Indies; *c*, *bleekeri*, 223 mm. specimen, Philippine Islands; *d*, *thompsoni*, 138 mm. specimen, Gilbert Islands; *e*, *guttatus*, 165 mm. specimen, Gilbert Islands; *f*, *leucopareius*, 156 mm. specimen, Hawaiian Islands; *g*, *nigroris*, 81 mm. specimen, Marshall Islands; *h*, *nigrofuscus*, 81 mm. specimen, Marshall Islands; *i*, *lineatus*, 150 mm. specimen, Gilbert Islands; *j*, *sohal*, 203 mm. specimen, Red Sea; *k*, *pyroferus*, 143 mm. specimen, Philippine Islands; *l*, *leucosternon*, 173 mm. specimen, Mauritius; *m*, *glaucopareius*, 143 mm. specimen, Marshall Islands; *n*, *achilles*, 137 mm. specimen, Phoenix Islands; *o*, *olivaceus*, 190 mm. spec-

worth noting at this time that they may be species which will not co-exist due to similarities in ecological tolerances (Gause, 1934). I suspect that this may be the explanation because of the apparent ease with which species of *Acanthurus* achieve wide distribution (probably because of long planktonic larval life). Since *A. olivaceus*, for example, ranges from the East Indies throughout Oceania, it would be expected to occur also in the Indian Ocean in view of existing current patterns.

The possibility that two species of *Ctenochaetus* may be mutually exclusive also bears checking. *C. magnus* Randall is known thus far from only three localities, Jarvis Island, Malden Island, and Cocos Island (off Costa Rica). The usually abundant *C. striatus* (Quoy and Gaimard) has not been collected from any of these islands, although it would not be expected at Cocos since this species does not appear to be among the few surgeon fishes to have crossed the Eastern Pacific Barrier (see Ekman, 1953).

One of the Atlantic species, *Acanthurus chirurgus* (Bloch) is very similar to the Indo-Pacific *A. xanthopterus* which occurs on the Pacific coast of Mexico and Central America, where it has usually been known by the name *Acanthurus crestonis* (Jordan and Starks). Although not included among the geminate species (listed by Jordan 1908: 76) which occur on either side of the isthmus of Panama, these two might qualify as another example.

The three Atlantic species which are common in the West Indies and Florida are occasionally taken as far north as New York and Massachusetts. It is believed that these species are not resident in such northern localities but represent individuals carried northward as larvae by the Gulf Stream.

The acronurus of *Acanthurus triostegus* is taken farther south on the southeast coast of Africa than are adults (Smith, 1949: 240 and by personal communication). The strong southerly current in this region is probably responsible. The same thing appears to be true of several species of surgeon fishes on the east coast of Australia (Whitley, 1953).

METHODS OF COUNTING AND MEASURING

Each ray of the dorsal and anal fins with a distinct base was counted regardless of how close adjacent rays might be. In cases where two rays branch from a common base, they were counted as one. At times dissection was necessary to determine whether the last two rays originate from a single basal element. Pectoral fin ray counts include the two uppermost unbranched rays, the first of which is a short bony spicule.

The gill rakers are small and occur in two distinct series, one on each side of the gill arch. Counts of both series are of diagnostic importance in *Acanthurus*. The usual gill raker counts are here designated anterior; those on the posteromedial side of the arch are called posterior. Gill raker counts were made on the first arch and include all rudiments. The raker counts were made on five specimens unless otherwise stated.

The scales are small and do not occur in regular rows. Successive trials at counting scales on the same specimen rarely resulted in the same count. The only scale counts which are recorded are those for the one new species.

The standard length is measured from the tip of the snout to the base of the caudal fin (end of hypural plate). All references to length of specimens are standard length. Head length is taken from the tip of the snout horizontally to a vertical at the most posterior end of the

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imen, Marshall Islands; *p*, *tennenti*, 115 mm. specimen, locality unknown; *q*, *fowleri*, 198 mm. specimen, Philippine Islands; *r*, *bariene*, 169 mm. specimen, Philippine Islands; *s*, *gahhm*, 179 mm. specimen, Phoenix Islands; *t*, *maculiceps*, 194 mm. specimen, Gilbert Islands; *u*, *auranticavus*, 205 mm. specimen, Philippine Islands; *v*, *grammoptilus*, 204 mm. specimen, Philippine Islands; *w*, *dussumieri*, 210 mm. specimen, Hawaiian Islands; *x*, *xanthopterus*, 200 mm. specimen, Gilbert Islands; *y*, *mata*, 228 mm. specimen, Wake Island; *z*, *monroviae*, 192 mm. specimen, Liberia; *aa*, *coeruleus*, 127 mm. specimen, Haiti; *bb*, *chirurgus*, 178 mm. specimen, Cuba; *cc*, *bahianus*, 168 mm. specimen, Cuba.

opercular membrane. Body depth is the distance from the natural groove at the base of the second anal spine to a similar groove at the base of the dorsal fin. Caudal concavity is the distance between vertical lines passing through the tips of the shortest middle caudal rays and the longest ray of the dorsal lobe of the caudal fin. This measurement is not made from a compressed or stretched caudal fin, but one in the normal resting position as shown in the figures of the various species.

ACANTHURUS Forskål

Acanthurus Forskål (1775: 59). Type species by subsequent designation (Jordan, 1917), *Chaetodon sohal* Forskål.

Body compressed, elliptic, the depth contained 1.55 to 2.5 in standard length; head length 3 to 4.3 in standard length; caudal peduncle with a single sharp folding spine on each side, fitting into a definite socket; length of caudal spine 1.9 to 13 in head length; least depth of caudal peduncle 1.9 to 3.1 in head length; mouth small, terminal, and only slightly protractile; jaws equal; teeth close-set, compressed, denticulate, 8 to 24 in upper jaw and 10 to 24 in lower jaw; dorsal fin with VI to IX (usually IX) spines and 22 to 33 rays; anal fin with III spines and 19 to 29 rays; pectoral fin rays 15 to 17; pelvic fin with I spine and 5 rays; caudal fin with 16 principal rays; caudal fin varying in shape from nearly truncate to very lunate; dorsal and anal fins continuous and unnotched; longest dorsal ray 3.5 to 6 in standard length; longest anal ray 3.8 to 7 in standard length; length of pectoral fin 2.7 to 3.8 in standard length; length of pelvic fin 3.2 to 5.5 in standard length; origin of pelvic fin at or slightly posterior to a vertical through middle of base of pectoral fin; diameter of eye in adults 2.8 to 5.7 in head length; interorbital space 2.5 to 3.6 in head length; snout length 3.9 to 8.2 in standard length; gill openings restricted to sides; gill membranes attached to isthmus; anterior gill rakers 13 to 29; posterior gill rakers 13 to 32; scales ctenoid, very small, and not in regular rows; head scaled, though not conspicuously; lateral line complete; 22 or 23 vertebrae; stomach varies from round and heavy-walled to elongate and thin-walled.

Agassiz (1833–43: vol. 4, p. 207, pl. J) discussed the osteology of *Acanthurus*. Günther (1861: 327) described the osteology of *Acanthurus triostegus*, and Gregory (1933: fig. 156) figured the skull of this species. Souche (1935) made an anatomical study of the musculature of the caudal spine of *Acanthurus chirurgus*. Willem (1944) studied the respiratory system of *Acanthurus triostegus* along with that of other species.

Plate 5, figures 3, 4, and 5 of Lütken (1880) represent the postacronurus, acronurus, and postlarval forms, respectively, of *Acanthurus coeruleus*. His figure 5 was drawn from a 5.7 mm. specimen. Weber (1913: fig. 70) figured a 7 mm. postlarval stage of an unidentified species of *Acanthurus*.

The genus *Acanthurus* is known by the common names surgeon fish, doctor fish, and tang. The species are, in general, herbivorous.

The gender of the name *Acanthurus* is uncertain. The probable derivation of this generic name is from the Greek *acantha* (thorn, fem.) and the Greek *oura* (tail, fem.). If properly latinized, it would have been *Acanthura*. Forskål, who proposed the name more-or-less as a subgenus and never used it in combination with a specific name, probably intended that it be masculine. Subsequent authors, including those who wrote primarily in latin, have consistently treated the genus as masculine, and I concur in this.

For a review of the generic synonymy of *Acanthurus* and a key to all the genera of the Acanthuridae, see Randall (1955*a*).

KEY TO THE SPECIES OF *Acanthurus* OF THE INDIAN AND PACIFIC OCEANS

(See page 165 for methods of counting and measuring.)

1a. Body light in color with vertical black bars; caudal fin truncate or slightly emarginate, caudal concavity contained more than 15 times in standard length; caudal spine very small 2

1b. Body not light in color with vertical black bars; caudal fin, at least in adults, emarginate to lunate, caudal concavity contained less than 15 times in standard length (except *guttatus*); caudal spine usually not small 3

2a. 6 vertical black bars (1 on head passing through eye; 4 on side of body; 1 on caudal peduncle); bars on side of about uniform width; anal soft rays 19 to 22; dorsal soft rays 22 to 24 (excluding fin ray counts of the species in Hawaii). (Indo-Pacific) . . . . **triostegus**

2b. 12 vertical black bars (4 on head, the longest passing through eye; 6 on side of body; 2 on caudal peduncle); bars on side about five times as broad dorsally as ventrally; anal soft rays 21 to 23; dorsal soft rays 23 to 25. (Réunion Island, Indian Ocean) (after Bleeker) . . . . **polyzona**

3a. Snout short, its length contained 6.6 to 8.2 times in standard length; mouth small and teeth small and numerous, 22 or more in lower jaw of adults 4

3b. Snout not short, its length contained 3.9 to 5.3 times in standard length; mouth usually not small (if small, not more than 12 teeth in lower jaw) and teeth not small and numerous, 22 or less (rarely 22) in lower jaw of adults 6

4a. Dorsal spines VI or VII; body depth 1.8 in standard length; anterior gill rakers 21; posterior gill rakers 24 (based on 1 specimen). (Philippine Islands and East Indies) . . . . **nubilus**

4b. Dorsal spines IX; body depth 2.1 to 2.5 in standard length; anterior gill rakers 13 to 17; posterior gill rakers 13 to 15 . 5

5a. Lengthwise blue lines on side of head and body (may be faded in preserved specimens); snout 6.6 to 7.1 in standard length; least depth of caudal peduncle 2.7 to 3 in head length; no dark brown spot just below axil of pectoral fin; maximum standard length about 300 mm. (Indo-West-Pacific, except Hawaii) . . . . **bleekeri**

5b. No lengthwise blue lines on side of head and body; snout 7.9 to 8.2 in standard length; least depth of caudal peduncle 2.2 to 2.5 in head length; a dark brown spot just below axil of pectoral fin; maximum standard length about 150 mm. (East Indies, Philippine Islands, and Oceania) . . . . . **thompsoni**

6a. Mouth low in origin on head and produced; a deep brown ring at base of caudal fin; all fins black. (Philippine Islands) (after Herre) . . . **mindorensis**

6b. Mouth not low in origin on head and usually not produced; no deep brown ring at base of caudal fin; all fins not black 7

7a. Posterior half of body and dorsal and anal fins with numerous white spots on a brown background; body with 3 vertical whitish bars, the first running from occiput to opercle, the second from base of third and fourth dorsal spines to region of anus, and the third from base of first few dorsal soft rays to base of first few anal soft rays; body very deep, greatest depth 1.5 to 1.6 in standard length. (Indo-West-Pacific) . . . **guttatus**

7b. Posterior half of body without numerous white spots; body without 3 vertical whitish bars; body not very deep, greatest depth 1.7 to 2.5 in standard length . 8

8a. A black spot at base of last few rays of both the dorsal and anal fins (spot in axial of anal fin in *leucopareius* very small) 9

8b. No black spot at base of last few rays of dorsal and anal fins **11**

9a. A whitish band, broadly bordered by dark brown bands, running from origin of dorsal fin across operculum just behind eye (faded in some specimens); caudal fin with no white posterior margin; caudal fin emarginate, caudal concavity 10.5 to 12 in standard length of adults; body depth 1.7 to 1.8 in standard length; anterior gill rakers 15 to 18. (Hawaiian Islands, Marcus Island, and Easter Island) . . . . **leucopareius**

9b. No whitish band running from origin of dorsal fin across operculum; caudal fin with a white posterior margin; caudal fin moderately concave to lunate, caudal concavity 4.5 to 10 in standard length; body depth 1.8 to 2.3 in standard length; anterior gill rakers 20 to 29 . . . . **10**

10a. Caudal fin moderately concave, caudal concavity 5.8 to 10.5 in standard length; black spot at axil of soft dorsal fin not large, its greatest width contained more than 2 times in diameter of eye; white posterior margin of caudal fin narrow, its width rarely less than 4 in pupil; no definite black margin around groove of caudal spine; body depth 1.8 to 2 in standard length; ends of median upper teeth rounded (Fig. 2*g*); maximum standard length about 200 mm.; no orange spots on head in life. (East Indies, Philippine Islands, and Oceania). . . . . **nigroris**

10b. Caudal fin lunate, caudal concavity 4.5 to 6 in standard length; black spot at axil of soft dorsal fin large, its greatest width contained less than 2 times in diameter of eye; white posterior margin of caudal fin not narrow, its greatest width about 2 in pupil (in specimens from Oceania); a definite black margin around groove of caudal spine; body depth 2 to 2.3 in standard length; ends of median upper teeth tend to be pointed (Fig. 2*h*); maximum standard length about 150 mm. (rarely over 120 mm.); orange spots on head in life (which usually fade in preservative). (Indo-West-Pacific) . . . . **nigrofuscus**

11a. Upper ¾ of body with conspicuous lengthwise black bands and in sharp contrast to uniform light grayish brown of lower ¼; caudal spine very long (1.9 to 2 in head length) and without a definite sheath; posterior gill rakers 13 to 15; anterior gill rakers 14 to 17 . . . . . **12**

11b. Body without conspicuous lengthwise black bands; caudal spine not very long (2.1 to 8 in head length) and with a definite sheath; posterior gill rakers 17 to 32; anterior gill rakers 16 to 29 . . . . . **13**

12a. Dorsal rays IX, 27 to 29; about 7 black lengthwise bands on body below lateral line (anteriorly), each bissected with a blue line and alternating with whitish (yellow in life) lines; median and pelvic fins not black. (Indo-West-Pacific, but not Hawaii) . . . . **lineatus**

12b. Dorsal rays VIII, 30 to 31; about 15 black lengthwise bands on body below lateral line (anteriorly), none bissected with blue lines and not alternating with whitish lines (the narrow intermediate lines of same color as ventral part of body); median and pelvic fins black. (Red Sea) . . . . **sohal**

13a. Lips reddish in life and surrounded (or nearly surrounded) by a pearly white line with a black band behind it; a bluish white band of about a half an eye diameter in thickness crossing chest slightly anterior to a vertical through center of eye; outer part of soft dorsal fin in life with 3 and anal fin with 2 narrow red lines alternating with bluish lines; pelvic fins brick red with black outer margin. (Philippine Islands) (after Herre) . . . . **leucocheilus**

13b. Lips not reddish in life and never completely surrounded by a pearly white line with a black band behind it; no bluish white band of about a half an eye diameter in width crossing chest; no red lines in outer part of soft dorsal and anal fins; pelvic fins not brick red with black outer margin **14**

14a. Dorsal spines VIII; caudal fin black except for a broad pale (yellow in life) band of near-uniform width on entire posterior margin (hence most of prolonged outer lobes of caudal fin pale); a white line under chin extending slightly above rictus; upper end of gill opening and edge of operculum broadly black; a diffuse orange area in life behind gill opening extending to axil of pectoral fin. (Indian Ocean, East Indies, Philippine Islands, and Western Oceania) . . . . **pyroferus**

14b. Dorsal spine IX; caudal fin not black with a broad pale posterior margin of uniform width; upper end of gill opening and edge of operculum not broadly black; no diffuse orange area in life behind gill opening extending to axil of pectoral fin **15**

15a. Mouth very small, its width from rictus to rictus contained 4.5 to 6 times in length of head; maximum number of upper or lower teeth 12; a white line under chin; depth of body 1.7 to 1.9 in standard length; dorsal soft rays 28 to 33; anal soft rays 26 to 29 . . . . **16**

15b. Mouth not very small, its width from rictus to rictus contained 3.2 to 4.8 times in length of head; maximum number of upper or lower teeth 22 (specimens over 50 mm. in standard length with at least 14 teeth in either jaw); no white line under chin; depth of body 1.9 to 2.5 in standard length; dorsal soft rays 23 to 28; anal soft rays 22 to 26. **18**

16a. Isthmus and chest with a chalky white band (as broad as depth of caudal peduncle) extending to base of pectoral fin; body bluish gray in preservative, head dark brown. (East Indies and Indian Ocean) . . . . **leucosternon**

16b. Isthmus and chest without a broad white band; body and head dark brown to black **17**

17a. No large elliptical pale yellowish area posteriorly on body; an oval white spot under eye; no white mark on opercular membrane; white line on chin extending above rictus; pale area at base of dorsal and anal fins very broad posteriorly; caudal fin emarginate, caudal concavity 10 to 14.5 in standard length; dorsal soft rays 28 to 31 (usually 29 or 30); anal soft rays 26 to 28 (usually 26 or 27). (East Indies, Philippine Islands, Oceania, and islands of tropical eastern Pacific) . . . . **glaucopareius**

17b. A large elliptical pale yellowish area (bright orange in life) posteriorly on body, enclosing in its hind part the caudal spine (this area absent in specimens less than about 65 to 70 mm. in standard length); no oval white spot under eye; an elongate pure white mark on opercular membrane; white line on chin not extending above rictus; pale area at base of dorsal and anal fins narrow and of almost uniform width; caudal fin lunate, caudal concavity 5.5 to 8.5 in standard length; dorsal soft rays 29 to 33 (usually 30 to 32); anal soft rays 26 to 29 (usually 27 to 29). (Oceania). . . . . **achilles**

18a. A prominent dark mark on shoulder (absent in young) **19**

18b. No dark mark on shoulder **25**

19a. Shoulder mark semicircular (open end forward at level of eye), a very elongate horizontal ellipse, or two elongate bands (one above the other); a large crescent-shaped white region posteriorly in caudal fin, its greatest width more than half the diameter of eye; base of caudal fin not pale; anal soft rays 22 to 24; dorsal soft rays 23 to 25; no fine longitudinal lines on body **20**

19b. Shoulder mark a spot, horizontal solid bar, or open triangle or semicircle (open part forward and below level of eye); no large crescent-shaped white region posteriorly in caudal fin (a white posterior margin, if present, of a maximum width of less than ⅓ eye diameter); base of caudal fin pale; anal soft rays 23 to 26; dorsal soft rays 24 to 28; fine longitudinal lines may or may not be present on body **21**

20a. Shoulder mark elongate with pale yellowish (bright orange in life) center; no dark area around caudal spine; white crescent in caudal fin with a narrow black posterior margin; brown portion of caudal fin with dark brown spots; color of young in life solid yellow (pale in preservative). (East Indies, Philippine Islands, and Oceania) . . **olivaceus**

20b. Shoulder mark semicircular with no pale center or (at a size of 100 to 110 mm. or more in standard length) 2 elongate black bands; a black, light bluish-bordered area around caudal spine (this area becoming relatively larger in larger specimens); white crescent in caudal fin without a black posterior margin; caudal fin without brown spots; color of young unknown to me. (Ceylon and Mauritius) . . . . **tennenti**

21a. Shoulder mark triangular or semicircular with uppermost part just above dorsal end of gill opening and lower part near axil of pectoral fin; posterior gill rakers 29 to 32. (East Indies and Philippine Islands) . . . . **fowleri**

21b. Shoulder mark a spot or solid bar; posterior gill rakers 17 to 28 . . . . **22**

22a. Shoulder mark a round black spot (just behind eye), at times with a narrow light bluish border; a blue line at base of dorsal fin in life, usually persisting as a bluish white line on preserved specimens; depth of body 1.9 to 2 in standard length. (East coast of Africa, East Indies, Philippine Islands, and Riu Kiu Islands) . . . . **bariene**

22b. Shoulder mark a black or dark brown bar; no blue line at base of dorsal fin in life; depth of body 2 to 2.2 in standard length **23**

23a. Caudal fin with a distinct white posterior margin, broader centrally, about ¼ eye diameter in maximum width; a long, pointed, black streak extending anteriorly from caudal spine (first appearing at a size of about 100 mm. and becoming progressively longer in larger specimens until it extends over half distance from caudal spine to base of pectoral fin); length of black shoulder bar (in specimen over 100 mm. in standard length) about 4.5 to 7 in standard length; numerous pale lengthwise lines not present on body; anal soft rays 24 to 26; dorsal soft rays 25 to 28. (Indo-West-Pacific) . . . . **gahhm**

23b. Caudal fin without a distinct white posterior margin; no long, pointed, black streak extending anteriorly from caudal spine; length of dark shoulder bar about 9 to 13 in standard length; numerous pale lengthwise lines present on body (faint on some specimens); anal soft rays 23 to 24; dorsal soft rays 24 to 26 . . . . **24**

24a. Head and nape with numerous prominent pale spots; upper distal part of pectoral fin with a large pale yellowish spot; shoulder mark in back of gill opening black (indistinct above and anterior to gill opening), horizontal, and usually somewhat pointed at end; dorsal fin with about 9 narrow longitudinal bands from base to margin; posterior gill rakers 21 to 24. (East Indies, Philippine Islands, and Gilbert Islands) . . . . **maculiceps**

24b. Head and nape without pale spots; upper distal part of pectoral fin without a large pale spot; shoulder mark dark brown (indistinct and narrow above gill opening), tilting sharply downward as it passes posteriorly, and rounded at end; dorsal fin without lengthwise bands or with only one or two posteriorly near outer border; posterior gill rakers 25 to 28. (Philippine Islands and East Indies) . . . . **auranticavus,** n. sp.

25a. Head with small pale (rust color in life) spots; black around caudal spine groove of adults extending ahead of front end of spine (to a distance almost as long as spine in a 245 mm. specimen); caudal fin with a very narrow white posterior margin (broader in young); body depth of adults (over 200 mm. in standard length) 2.2 to 2.5 in standard length. (northern Australia) . . . **grammoptilus**

25b. Head without small pale spots; dark brown or black around groove of caudal spine not extending much beyond front end of spine; caudal fin without a narrow white posterior margin (except in young which may have a very narrow pale margin); body depth of adults 1.9 to 2.1 in standard length 26

26a. Caudal fin marked with numerous blackish spots; sheath of caudal spine whitish and in sharp contrast to black surrounding caudal spine groove; a pale (yellow in life) band crossing or nearly crossing interorbital space from eye to eye; body with numerous, fine, slightly wavy, pale bluish, lengthwise lines which usually persist in preservative; dorsal fin of adults without alternating dark and light bands or with only a few faint narrow ones in outer portion of fin; eye large, its greatest diameter contained in head length about 3.2 to 4.7 times over the range in standard length of 120 to 300 mm.; anal soft rays 24 to 26. (Indo-West-Pacific) . . . . **dussumieri**

26b. Caudal fin not marked with blackish spots; sheath of caudal spine brownish; no pale band crossing interorbital space (a pale yellowish area may extend anteriorly from eye but not as a definite band); body without numerous slightly wavy, fine, pale bluish, lengthwise lines (lines, if present, indistinct and broken or coarse and very wavy and rarely evident in preserved specimens); dorsal and anal fins with lengthwise dark brown (blue in life) bands alternating with light brown (yellow in life) bands from base to margin (may fade in preservative, especially in *mata*); eye not large, its greatest diameter contained about 3.9 to 5.4 times in head length over the range in standard length of 120 to 300 mm.; anal soft rays 23 to 25 . . 27

27a. Outer ⅓ of pectoral fin pale (yellowish in life) and contrasting with darker basal ⅔ of fin (in specimens over about 120 mm. in standard length); dorsal fin with about 4 broad lengthwise bands; caudal fin very lunate, caudal concavity about 4.5 to 7 in standard length; caudal spine usually small, about 4.5 to 5.5 in length of head; dark margin around socket of caudal spine usually narrow and indistinct; white band at base of caudal fin usually not distinct; anterior gill rakers 16 to 22; posterior gill rakers 17 to 22. (Indo-Pacific) . . . . **xanthopterus**

27b. Pectoral fin uniform brown; dorsal fin (at least in Hawaiian specimens) with about 8 narrow lengthwise bands; caudal fin not very lunate, caudal concavity about 6 to 10 in standard length; caudal spine usually not small, about 3 to 4.2 in length of head; a definite dark brown or black margin around socket of caudal spine forming an area about twice as high as maximum width of spine; white band at base of caudal fin usually distinct; anterior gill rakers 21 to 25; posterior gill rakers 23 to 25. (Indo-West-Pacific) . . . . **mata**

KEY TO THE SPECIES OF *Acanthurus* OF THE ATLANTIC OCEAN

1a. Body very pale with 6 vertical black bars, the first passing through eye, the last dorsally on caudal peduncle; anal soft rays 19 to 21; dorsal soft rays 22 to 24. (Indo-Pacific, one record from West Africa) . . . . **triostegus**

1b. Body not very pale with 6 vertical black bars; anal soft rays 22 to 26; dorsal soft rays 24 to 28 2

2a. A very large pale (yellow or orange in life) spot on caudal peduncle with caudal spine in center. (West Africa) . . . . **monroviae**

2b. No large pale spot on caudal peduncle. 3

3a. Anal soft rays 24 to 26; dorsal soft rays 26 to 28 (usually 27); body depth about 1.7 in standard length; no narrow dark area around caudal spine; sheath of caudal spine pale; body purplish in life with conspicuous lengthwise lines (in young bright yellow without lines); anterior gill rakers 13 to 14 . . . . **coeruleus**

3b. Anal soft rays 21 to 23; dorsal soft rays 23 to 26 (rarely 26); body depth about 2 in standard length; a narrow dark area (blue in life) around caudal spine; sheath of caudal spine dusky; body light to dark brown in life with or without faint narrow lengthwise lines; anterior gill rakers 16 to 19 4

4a. Eight to 12 dark brown vertical bars on side of body; caudal fin emarginate (nearly truncate in young), caudal concavity contained about 14 to 18 times in standard length; caudal fin without a definite white posterior margin; outer ⅓ of pectoral fin pale in adults; no fine lengthwise lines on body; posterior gill rakers 15 to 18 . . . . **chirurgus**

4b. No dark brown vertical bars on side of body; caudal fin lunate, caudal concavity contained about 5 to 12 times in standard length; caudal fin with a whitish posterior margin, broadest centrally (about ¼ to ⅓ pupil diameter in width in adults, greater in young); outer ⅓ of pectoral fin not distinctly paler than rest of fin; fine lengthwise lines on body (which usually fade in preservative); posterior gill rakers 22 to 24 . . . . **bahianus**

Acanthurus triostegus (Linnaeus)

Figs. 1*a*, 2*a*, 3, 4

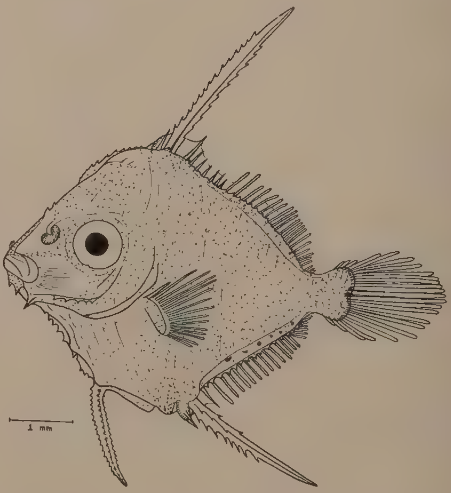


FIG. 3. Postlarval *Acanthurus triostegus sandvicensis*. Drawn with the aid of a camera lucida by Helen A. Randall (specimen taken in a plankton tow, offshore, Hawaiian Islands).

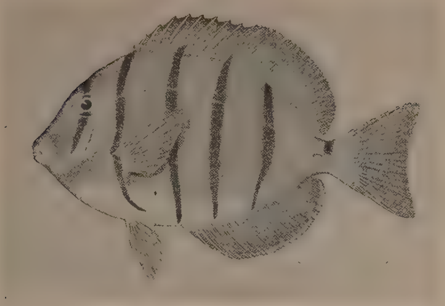


FIG. 4. *Acanthurus triostegus sandvicensis* (after Jordan and Evermann, 1905, retouched).

Chaetodon triostegus Linnaeus (1758: 274) (Indies).

Harpurus fasciatus Forster (1788) (reference after Jordan 1917).

Acanthurus Triostegus Bloch and Schneider (1801: xxxviii, 215) (Indian and Pacific Oceans).

Acanthurus zebra Lacépède (1802: 546) (Pacific Ocean and East Indies).

Chaetodon couaga Lacépède (1802: 726, 727, pl. 6, middle fig.).

Teuthis australis Gray (1827: 435) (Australia).

Acanthurus hirudo Bennett, J. W. (1828: pl. 11) (Ceylon).

Acanthurus triostegus Cuvier and Valenciennes (1835: 197) (Mauritius, Seychelles, Marianas, New Zealand, Oualan, Society Islands, and Hawaiian Islands); Bleeker (1850*a:* 13) (Batavia, Java); Günther (1861: 327) (East Indies, New Hebrides, Mauritius, New Zealand, west coast of Australia, and Hawaiian Islands); Playfair *in* Playfair and Günther (1866: 56) (Zanzibar); Günther (1873: 108) (Indian Ocean and Polynesia); Day (1876: 204, pl. 48, fig. 2) (seas of India); Macleay (1881: 527) (west coast of Australia); Steindachner (1882: 54) (Congo Coast, West Africa); Hilgendorf (1883: 43); Day (1889: 139, fig. 54); Waite (1894: 217) (Maroubra, New South Wales); Waite (1897: 187) (Funafuti, Ellice Islands); Weber (1913: 316) (East Indies); Herre (1927: 407, pl. 1, fig. 1) (Philippine Islands and Guam); Herre (1936: 240) (Cocos Island off Costa Rica, Marquesas Islands, Tuamotu Archipelago, Tahiti, Fiji Islands, and New Hebrides); Brock (1943: 130) (Tres Marias Islands, Mexico); Schultz (1943: 162) (Phoenix and Samoa Islands); Smith (1949: 240, pl. 33, no. 608) (east coast of Africa south to Zululand); de Beaufort (1951: 144) (East Indies); Harry (1953: 146) (Raroia, Tuamotu Archipelago).

Acanthurus triostegos Swainson (1839: 255) (error for *triostegus*).

Acanthurus Subarmatus Bennett, F. D. (1840: 278, fig.) (Society Islands).

Acanthurus pentazona Bleeker (1850*a:* 4, 13) (Batavia, Java); Bleeker (1850*b:* 107) (Batavia, Java); Günther (1861: 329).

Rhombotides triostegus Bleeker (1863*b:* 235) (Ternate, East Indies).

Rhombotides pentazona Bleeker (1865: 288) (Ambon, East Indies).

Acanthurus triostegus var. *sandvicensis* Streets (1877: 67) (Honolulu).

Acanthurus zebra DeVis [not of Lacépède] (1883: 447) (Duke of York Group = Tokelau Islands).

Teuthis triostegus Jordan and Evermann (1898: 1690) (Clarion and Socorro Islands, western Mexico); Seale (1901: 108) (Guam); Jordan and Evermann (1902: 357) (Kotosho Island, Formosa); Jordan and Fowler (1902: 552) (Okinawa); Kendall and Goldsborough (1911: 309) (Tuamotu Archipelago and Marshall Islands); Kendall and Radcliffe (1912: 144) (Manga Reva); Barnard (1927: 778, pl. 31, fig. 5) (Natal coast, Africa); Marshall, T. C. (1941: 62) (Moreton Bay and Townsville, Queensland); Fowler (1944*b:* 172) (New Hebrides); Fowler (1945: 66) (Saipan).

Teuthis elegans Garman (1899: 70, pl. L, fig. 2) (Cocos Island off Costa Rica).

Teuthis sandvicensis Jenkins (1903: 479) (Hawaiian Islands); Snyder (1904: 533) (Hawaiian Islands); Fowler (1941: 257) (Oahu); Fowler (1949: 104).

Hepatus sandvicensis Jordan and Evermann (1905: 394, fig. 172) (Hawaiian Islands); Jordan and Seale (1906: 354) (Hawaii).

Hepatus triostegus Snodgrass and Heller (1905: 403) (Revillagigedo Islands and Cocos Island); Jordan and Seale (1906: 354) (Samoa); Steindachner (1906: 1392) (Samoa Islands); Ogilby (1916: 184) (coast of Queensland); Fowler and Silvester (1922: 124) (Samoa); Fowler and Ball (1925: 19) (Laysan, Lisiansky, French Frigate Shoals, and Necker Island in the Hawaiian Archipelago, Johnston Island, and Wake Island); Fowler (1928: 264, pl. 31, fig. A) (Indo-Pacific); Fowler and Bean (1929: 249) (Indo-Pacific); Fowler (1932: 10) (Marquesas Islands); Seale (1935: 364) (Solomon Islands); Fowler (1938: 173, 184) (Bora Bora and Tongareva); Pietschmann (1938: 26, pl. 4) (Molokai and Pearl and Hermes Reef, Hawaiian Archipelago); Schmidt and Schultz (1940: 8) (Clipperton Island); Hiyama (1943: 95, pl. 20, fig. 57) (Marshall Islands); Aoyagi (1943: 216, pl. 6, fig. 16, teeth only) (Riu Kiu Islands); Kamohara (1954: 52) (Tokara Islands, southern Japan).

Acanthurus sandvicensis Jordan and Jordan (1922: 66) (Hawaiian Islands); Schultz and Woods (1948: 248, fig. 1, A) (Hawaiian Islands and Johnston Island).

Teuthis troughtoni Whitley (1928: 233, pl. 16, fig. 1) (Vanikoro, Santa Cruz Islands); Whitley and Colefax (1938: 294, fig. 3) (Nauru Island and Ocean Island); Fowler (1946: 197) (Riu Kiu Islands).

Acanthurus triastegus Borodin (1932: 87) (Samoa, Bora Bora, and Raiatea) (error for *triostegus*).

Acanthurus triostegus triostegus Schultz and Woods (1948: 249, fig. 1, B) (Indo-Pacific); Schultz and Woods *in* Schultz *et al.* (1953: 624, fig. 90, b, d, e, pl. 63, A, B, C, pl. 64, A, B, C) (Marshall and Mariana Islands).

Acanthurus triostegus marquesensis Schultz and Woods (1948: 250, fig. 1, C, F) (Marquesas Islands).

Dorsal rays IX, 22 to 24 (except in the Hawaiian Islands where the soft rays range to 26); anal rays III, 19 to 22; pectoral rays 14 to 16; anterior gill rakers of eight specimens from the Marshall Islands 19 to 22; posterior gill rakers 20 to 24; anterior gill rakers of eight specimens from the Hawaiian Islands 18 to 22; posterior gill rakers 19 to 22; a 54 mm. specimen has 12 upper and 14 lower teeth; a 134 mm. specimen has 14 upper and 16 lower teeth; a 158 mm. specimen has 16 upper and 18 lower teeth.

Very rarely specimens were found with VIII dorsal spines, but these could be recognized as abnormalities. The specimen reported with VIII dorsal spines from Tahiti by Schultz and Woods (1948: 250), for example, has a broad gap between its seventh and eighth spines.

Color (in life) light olivaceous gray, shading to white ventrally, with six narrow vertical black bars on head and body, the first running through eye, the second from origin of dorsal fin to base of pectoral fin, and the last dorsally on caudal peduncle; fins olivaceous gray except for margins of anal and pelvic fins which are white. Often there is a sharp demarcation between the gray color of about the upper five-sixths of the body and the pure white lower sixth, and there may be a narrow irregular dark line dividing these two colors. Schultz and Woods (1948: 248) attribute this line and the abrupt transition to white to breeding coloration. I am unable to confirm this finding, for I have observed numerous specimens with the gonads only slightly developed which exhibit this color pattern.

It was noted that specimens of *A. triostegus* from coral atolls or low-lying coral islands had narrower vertical bars on the side of the body than specimens from high islands. In 20 specimens 110 mm. or more in standard length from low islands (10 of which were collected from Midway, Laysan, French Frigate Shoal, and Johnston Island) the width of the central bar of the body (as measured midlaterally) is contained 3.3 to 8.2 times in the greatest diameter of the eye; the mean is 5.27. The width of the bar into the eye in 20 specimens of comparable size from high islands (including the Hawaiian Islands) is 1.7 to 3.9 with a mean of 2.65. Seven specimens from a tidal pond on the island of Hawaii were strongly melanistic, and the bar width was contained in the eye diameter 1.25 to 1.8 times with a mean of 1.43. The water in this pond was clear, and the bottom was black basalt with no coral and little algae. Around coral islands the bottom is notable for being light in color. The littoral area of volcanic islands is considerably darker, in general, due to the dark brown to black color of basalt. The above mentioned tidal pond on Hawaii is unusually dark. It is therefore believed that the width of the black bars of *A. triostegus* is correlated with the degree of darkness of the substrate. This is in agreement with the well-known phenomenon of increased production of melanophores from a dark background (Breder and Rasquin, 1952: 19).

Schultz and Woods (1953: pl. 64, A, B, C) have photographs of the postacronurus and juvenile stages of *A. triostegus*.

The 5.5 mm. postlarval specimen (Fig. 3) of *A. triostegus* was taken in a plankton tow with a 1 meter net offshore from the Hawaiian Islands by personnel of the Pacific Oceanic Fishery Investigations.

Streets (1877: 67) first called attention to the differences in color between *A. triostegus* in the Hawaiian Islands and elsewhere in its range; he designated the Hawaiian form as variety *sandvicensis*. It has an elongate black streak at the base of the pectoral fin, a vertical black bar dorsally on the caudal peduncle which reaches almost to the mid-lateral line but usually has no black spot on the peduncle below this bar; there is no definite black line mid-dorsally on the head. From the rest of its range specimens have a single black spot, two black spots, or a short bar at the pectoral base; the vertical black bar on the caudal peduncle is usually more restricted to the dorsal part and there is a black spot or short bar ventrally on the peduncle; a median black line is usually evident on the head.

Schultz and Woods (1948: fig. 1) diagrammed the different color marks at the base of the pectoral fin of *A. triostegus* and tabulated the dorsal, anal, and pectoral fin ray counts of samples from a number of localities. They demonstrated the higher fin ray counts of the species in Hawaii; however they pointed out the possibility that cooler water in the Hawaiian Islands may be the cause of these higher counts. Nevertheless, these authors (and others) regarded the Hawaiian form as a full species, *Acanthurus sandvicensis*. In view of the marked geographical separation of the Hawaiian chain from other major island groups, at least slight differences are to be expected in Hawaiian populations of reef fishes. Since there is no possibility of readily testing whether Hawaiian stocks will freely interbreed with those of other areas, the task of making inferences of degree of interfertility from the observed morphological differences must be made. In my opinion the differences of *A. triostegus* in the Hawaiian Islands are not of sufficient magnitude to warrant their recognition as a basis of a species. Because of the frequent use of the name *sandvicensis*, however, I prefer to retain this as a subspecific designation for the species in Hawaii.

I have made dorsal and anal fin ray counts of *A. triostegus* from various localities (Table 2) in order to note variation from area to area and in the hope of shedding light on the question of whether water temperature has any effect on the number of fin rays. Unfortunately the number of specimens are too few in some important localities to be certain whether the apparent differences are real or due to chance. Other difficulties bear mentioning. Cooler temperatures, when correlated with high fin ray counts, might seem to be the cause of the high counts; however these might be a manifestation of the differentiation of populations in different areas. Unless counts are made from small juveniles from such regions, the temperature at which the number of fin rays was fixed during development could not be estimated with any degree of assurance. Even more disturbing is the problem of fin ray counts made from specimens from colder areas in the path of currents from warm regions. If the counts were made from individuals of a resident population, they would reflect possible temperature effects of the area. If, however, the counts were made from fish carried as larvae from a warmer area, such an interpretation would be erroneous. The duration of the planktonic larval life of *A. triostegus* in the Hawaiian Islands has been estimated as two and one-half months (Randall, MS). Larvae of *A. triostegus* could float from the Philippines to Japan in about half this time (computed from current velocities given by Sverdrup, Johnson, and Fleming, 1946: 720). Therefore, the fin ray counts of specimens from S. Africa, New South Wales, Okinawa, and S. Japan are here not considered with respect to temperature effects on the number of fin rays.

Disregarding those areas in Table 2 in which a single specimen was available for fin ray counts, there remain eleven regions where average monthly sea surface temperatures (based on Hydrographic Office Pub. No. 225) may dip to 78° F. or lower at least one month of the year. These are Mauritius, Ningpo, China (the southerly current along the coast of China permits consideration of this locality but not Okinawa or S. Japan which are directly in the path of the Kuroshio), Marcus Island, Tahiti, Tuamotu Archipelago, Mangareva, possibly the Marquesas Islands, Galapagos Islands, Clarion Island, Hawaiian Archipelago, and Johnston Island. In seven of these regions (Mauritius, Marcus, and the Tuamotus excepted) the counts tend to be high; the number of specimens in the samples with 21 or more anal rays exceeds or is equal to the number with 20 rays. Four of these seven regions, Ningpo, Mangareva, Galapagos, and Clarion have a month in which the average sea surface temperature is 72° or less. With the exception of Galapagos, these are all areas in which the samples display a definite increase in fin ray counts. Although more counts are needed from these and other colder areas and more precise information on temperature, the data suggest that cool water is correlated with high dorsal and anal fin ray counts of *A. triostegus*.

The fin ray counts of specimens of *A. triostegus* from the principal Hawaiian Islands (Kauai to Hawaii) seem higher than might be expected from the annual range of average monthly sea surface temperatures (normally about 75° to 82° F. as based on U. S. Coast and Geodetic Survey Pub. TW-2). The dorsal rays, for example, are apparently higher than those from specimens in any other region given in Table 2 except possibly Ningpo, China. Moreover, the counts of the dorsal and anal rays of specimens from Midway to French Frigate Shoal are not higher than the Hawaiian Islands proper in spite of lower temperatures in the Leeward group (about 70° to 80° F.). This suggests that the greater number of fin rays in the Hawaiian Archipelago may be due to genetic factors; the usual temperature variation within this chain of islands may not influence the number of rays. This is consistent with the color differences of the species in the Hawaiian Islands as given above. These color differences are probably genetically governed, for no specimens from colder areas other than the Hawaiian chain were seen with typical *sandvicensis* markings.

Fowler (1927*b:* 20) noted that there was a dark streak at the base of the pectoral fin of specimens from Fanning Island in the Line Islands. I examined two of his specimens at the Bishop Museum. One of these, 109 mm. in standard length, has a definite 10 mm. streak in which the eye diameter is contained 1.2 times. This is only about half the length of the usual *sandvicensis* streak, however.

Other slightly streaked specimens were found among the collections from the Line Islands and the Phoenix Islands (and to a lesser extent in some juveniles from Tahiti).

The most pronounced streaks, 1.25 to 1.5 eye diameters in length, were seen on five specimens, 41 to 61 mm. in standard length, from Enderbury Atoll. These specimens were from the sample from which the high fin ray counts recorded in Table 2 were made. These counts are the highest of all the samples from warm water regions in the table. The streaked specimens did not exhibit higher numbers of dorsal or anal rays than those with typical *triostegus* coloration. The same applies to other specimens with short streaks (or elongate spots) from the Phoenix and Line Islands.

The tendency to streaking at the base of the pectoral in island groups to the south of Hawaii might somehow be due to interbreeding effects from larvae carried to these areas from the Hawaiian Islands or Johnston Island. Admittedly this is difficult to explain in terms of existing current patterns because of the strong westerly component of the equatorial currents. Transport back to the east in the counterequatorial does not appear to provide the answer, for it would seem that larvae would be carried at least to the Marshall Islands before the counterequatorial could possibly be reached; thus one would expect to find any effects of interbreeding to be most pronounced in the Marshall Islands. This, however, is not the case.

TABLE 2

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus triostegus* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS					ANAL SOFT RAYS			
	22	23	24	25	26	19	20	21	22
Natal, S. Africa	2	6	1				6	3	
Mauritius	7	9	2			2	11	5	
S. India	1		1				2		
Siam		1					1		
Maroubra Bay, New South Wales	1	1	1				1	2	
East Indies and Philippines	4	6				1	8	1	
Okinawa	1	6	2				4	5	
Ningpo, China (29.5° N)		3	9					7	5
S. Japan (30.4° N)		3					2	1	
Palau Islands	2	7	6				10	5	
Solomon Islands	1	1					2		
Fiji Islands		1					1		
Samoa Islands	3	16	6			1	16	8	
Gilbert Islands	9	22	2			3	19	11	
Marshall Islands	10	31	4			5	28	12	
Wake Island	3	14	2				12	7	
Marcus Island		3	1				4		
Mariana Islands	2	19	4			2	18	5	
Cook Islands		1					1		
Tubuai Islands		1					1		
Tahiti	1	12	8			1	10	10	
Tuamotu Archipelago	1	9	1				7	4	
Mangareva	1	2	2				2	1	2
Marquesas Islands	1	8	5				6	8	
Phoenix Islands									
Hull and Canton	6	35	11			1	38	13	
Enderbury	1	7	7				3	10	2
Baker Island	1	2				1	1	1	
Line Islands									
Palmyra	6	28	7			4	28	9	
Fanning		4	1				3	2	
Washington and Christmas		6					6		
Galàpagos Islands	1	3					2	2	
Cocos Island (Costa Rica)	2	6	1			2	5	2	
Clipperton Island		1					1		
Clarion Island	3	6	5			2	4	8	
Gulf of California		1				1			
Hawaiian Archipelago									
Kauai to Hawaii	1	36	59	5	1		15	72	15
Midway to French Frigate Shoal	1	17	17				7	27	3
Johnston Island		5	15	3			1	18	4

The size of the transforming acronurus larva of *A. triostegus*, again suggests genetic influence of Hawaiian populations in islands to the south. The acronurus or late postlarval form of *A. triostegus* enters tide pools to transform to the juvenile stage. Due to the accessibility of tide pools for collecting and the abundance of the species, the transforming stage often appears in museum collections. Fifty-six such specimens from the East Indies, Palaus, Marianas, and Gilbert Islands, all very warm regions of the Pacific, range in standard length from 19 to 25 mm. and have a mean length of 21.7 mm. The 42 available specimens of the transforming acronurus stage were measured from the following cooler regions of the Pacific: Ningpo, Marcus Island, Tahiti, Tuamotu Archipelago, Mangareva, Marquesas, and Clarion Island. The standard length of these range from 22.5 to 26.5 mm. with a mean of 24.8 mm. The larger average size of the acronuri developing in cooler water is probably a temperature effect. Seventy-seven transforming specimens from the Hawaiian Islands vary from 23 to 29.5 mm. in standard length, with a mean length of 25.9 mm. This is higher than one might expect if the average postlarval size were wholly dependent on temperature. Twenty-two specimens from the Phoenix Islands vary from 23 to 27 mm. and have a mean standard length of 24.9 mm. Only two specimens were found in collections from the Line Islands; these measured 23.5 and 24 mm. in standard length. The large size in the Phoenix Islands (and possibly also in the Line Islands) is not consistent with the sea surface temperatures of these groups (in excess of 80° F. throughout the year). These islands are no more geographically isolated than most of the other islands of the Pacific where the sea surface temperatures are warm, so there is no reason to suspect any marked population differentiation.

The largest specimen of adult *Acanthurus triostegus* examined by me was one of a series of 17 caught by personnel of the Pacific Oceanic Fishery Investigations with a beach seine at Midway Island. It measured 213 mm. in standard length. Twelve others in the sample ranged from 174 to 206 mm. in standard length. Of over 5,000 adult specimens caught in traps off Oahu, the longest was 175 mm. in standard length. The colder water at Midway may be the principal basis for the larger size at this locality. In a small collection from Clarion and Socorro in the Revillagigedo Islands (Mexico) there are two large specimens measuring 187 and 188 mm. in standard length. The water around these islands is also cool. Of 905 specimens reported by Schultz and Woods (1953: 624) from the Marshall Islands and Marianas, the largest was 152 mm. The species appears to be small in other warm areas of the Pacific except the Line Islands and the Phoenix Islands where specimens as large as 189 mm. in standard length have been taken.

The range of *Acanthurus triostegus*, as is apparent from the above discussion, is very extensive. This species is in continuous distribution from East Africa to the tropical Pacific; it is one of the three species of the genus *Acanthurus* to have crossed the eastern Pacific barrier. It is recorded from the Galapagos Islands, Cocos Island off Costa Rica, and Clipperton Island, the Revillagigedo Islands, and Tres Marias Islands off the coast of Mexico. Vernon E. Brock has informed me that the species is rare at islands off the coast of Mexico. Boyd W. Walker kindly loaned a 94 mm. specimen collected by M. A. Newman and J. E. Fitch from Frailes Bay, Gulf of California. This is the first record from the coast of North America.

There is one record of *A. triostegus* from the Atlantic Ocean, that of Steindachner (1882: 54) from the Congo coast of Africa. Further records are needed to substantiate this.

Schultz and Woods (1948: 250) observed a much higher incidence of specimens of *A. triostegus* with two spots at the base of the pectoral fin than with a single spot or bar in the Marquesas Islands; these authors proposed the subspecific name *marquesensis* for the species in this group of islands.

It is interesting to note that neither this nor the Hawaiian subspecies has reached the coast and continental islands of America. Instead, the eastern Pacific form is *A. triostegus triostegus* which is found in the Line Islands and elsewhere in Oceania (except Hawaii and the Marquesas). This supports the contention of Herre (1940) that the counterequatorial current would seem to be the only possible mode of transport of Indo-West-Pacific fishes to the American coast. Jordan and Seale (1906: 354), Herre (1927: 409), and de Beaufort (1951: 147) are probably all in error in stating that the *sandvicensis* form of the species occurs at islands offshore from Mexico. All of the specimens which I have seen from such islands have a single black spot at the pectoral base, or occasionally two spots, or a short bar.

De Beaufort (1951: 147) stated that the typical form of *Acanthurus triostegus* occurs together with the subspecies *sandvicensis* in the Hawaiian Islands. The basis for his statement is probably the information from Fowler (1928: 265) to the effect that the brown band in some specimens of the *sandvicensis* form does not continue below the pectoral base. I have never seen a specimen of *A. triostegus* from the Hawaiian Islands on which the brown streak does not continue below the base of the pectoral fin. Considerable variability may be observed in this marking, however, and it is conceivable that very rarely a specimen might be found with only a short bar at the pectoral base. Often the streak is interrupted such that a short bar at the pectoral base is separated from the larger part of the streak below. The streak may even be broken into three separate segments.

Acanthurus polyzona (Bleeker)
Fig. 5

Rhombotides polyzona Bleeker (1868*a:* 277) (Réunion); Bleeker *in* Bleeker and Pollen (1874: 44, pl. 12, fig. 2).

Acanthurus triostegus var. *polyzona* Peters (1876: 439).

Acanthurus polyzona Sauvage (1891: 519).

Dorsal rays IX, 23 to 25; anal rays III, 21 to 23; pectoral rays 16; eight or nine teeth on each side of upper jaw and nine or ten on each side of lower jaw.

Bleeker described the color in life as olivaceous on the back and olivaceous-silvery ventrally, with vertical black bars as follows: the first rostro-frontal on head (not very evident in figure), the second maxillo-ocular, the third oculo-interopercular, the fourth opercular, the next six on the body proper, and the last two on the caudal peduncle.

This species seems to be closely allied to *A. triostegus*, sharing with it the slightly emarginate caudal fin, low number of dorsal and anal fin rays, small caudal peduncle spine (as based on the figure in Bleeker and Pollen) and barred color pattern. Unlike the bars of *A. triostegus*, those of *A. polyzona* are more numerous and much broader dorsally than ventrally.

Acanthurus polyzona is apparently known only from the island of Réunion in the Indian Ocean. I have seen no specimens of this species.

Acanthurus nubilus (Fowler and Bean)
Figs. 2*b*, 6

Hepatus (*Harpurina*) *nubilus* Fowler and Bean (1929: 253, fig. 15) (Dodepo Island, Celebes).

Harpurina nubilus de Beaufort (1951: 166, fig. 27).

Dorsal rays VI, 27; anal rays III, 24; pectoral rays 16; anterior gill rakers 21; posterior gill rakers 24; 24 upper teeth; 28 lower teeth. These counts are based on the holotype, 153 mm. in standard length. Other specimens of this species reported on by Fowler and Bean were not located. These authors recorded the number of dorsal spines as VI or VII.

Mouth small, its width as measured from rictus to rictus contained 3.8 times in head

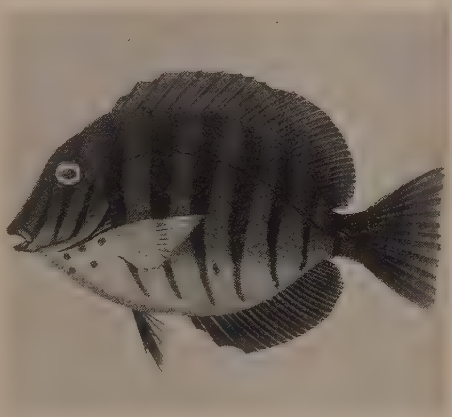


FIG. 5. *Acanthurus polyzona* (after Bleeker and Pollen, 1874).

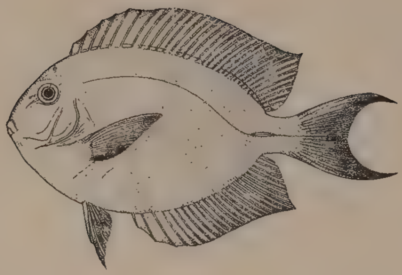


FIG. 6. *Acanthurus nubilus* (after Fowler and Bean, 1929).

length; snout short, snout length 6.8 in standard length; depth of body 1.8 in standard length; head length 4.1 in standard length; least depth of caudal peduncle 1.8 in head length; diameter of eye 3 in head length; caudal concavity 6.7 in standard length.

Color given by Fowler and Bean, for specimens other than the type, is as follows: "Nearly black, shading to brown under scales, probably dark seal brown with slaty streaks in life, of which usually 2 to each scale row. On side of head and breast brown in form of hexagonal spots in pale ground color, spots size of number 6 shot. No black shoulder blotch or black spots in axils of verticals. Fins nearly black. Dorsal with oblique bars extending upward and backward, best seen in reflected light. Oblique bars very indistinct on anal. Caudal without markings. Pectoral membranes hyaline."

Color (in alcohol) of holotype uniformly brown except membranes of pectoral fin which are hyaline.

This species is known only from Buka Buka Island in the Gulf of Tomini, Celebes, and Dodepo Island, Celebes.

A. nubilus is related to *A. thompsoni* and *A. bleekeri*. These three species of *Acanthurus* are distinctive in having small mouths, small teeth, and a moderately large eye which is set more toward the center of the head than other species in the genus.

Were it not for *A. thompsoni* and *A. bleekeri*, *A. nubilus* would probably best be placed by itself in the genus *Harpurina* because of the above characteristics and its VI or VII dorsal spines. The former species possess the usual IX dorsal spines and serve to connect *A. nubilus* with more typical *Acanthurus*.

Acanthurus bleekeri Günther

Figs. 2*c*, 7

Acanthurus mata. Bleeker (*non* Cuvier and Valenciennes) (1854*b:* 432) (Java); Aoyagi (1943: 206, pl. 4, fig. 9, teeth only).

Acanthurus bleekeri Günther (1861: 335) (after Bleeker); Herre (1927: 423, pl. 14, fig. 2) (Philippine Islands); de Beaufort (1951: 162) (East Indies); Schultz and Woods *in* Schultz *et al.* (1953: 636) (Rongelap Atoll, Marshall Islands).

Rhombotides Bleekeri Bleeker (1863*a:* 153) (Halmahera, East Indies).

Acanthurus Bleekeri Klunzinger (1871: 509) (Red Sea).

Acanthurus aurolineatus Day (1876: 204, pl. 48, fig. 3) (Coromandel coast of India); Day (1889: 139).

Acanthurus (*Rhombotides*) *Bleekeri* Klunzinger (1884: 85) (Red Sea).

Harpurus gnophodes Fowler (1904: 544, pl. 22, upper fig.) (Padang, Sumatra).

Teuthis mata. Kendall and Goldsborough (1911: 310) (Tuamotu Archipelago).

Acanthurus Güntheri Weber (1913: 317) (Ambon, East Indies).

Hepatus weberi Ahl (1923: 317) (new name for *Acanthurus Güntheri* Weber).

Hepatus bleekeri Fowler (1928: 270) (Sumatra and Fakarava, Tuamotu Archipelago); Fowler and Bean (1929: 220) (Philippine Islands and East Indies); Hiyama (1943: 94, pl. 19, fig. 54).

Teuthis bleekeri Fowler (1949: 102).

Acanthurus weberi de Beaufort (1951: 163) (East Indies).

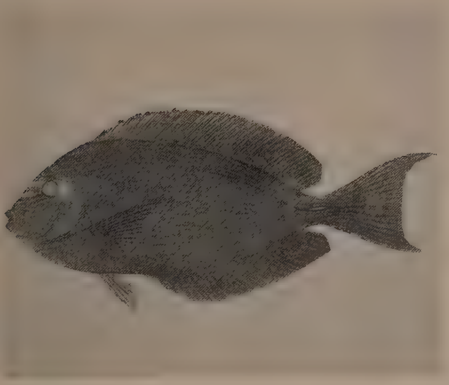


FIG. 7. *Acanthurus bleekeri* (after Hiyama, 1943).

Dorsal rays IX, 24 to 26; anal rays III, 23 or 24; pectoral rays 16 or 17; (usually 17); anterior gill rakers 13 to 15 and posterior gill rakers 13 to 15 (gill raker counts from Philippine specimens); a 71 mm. specimen has 14 upper and 16 lower teeth; a 146 mm. specimen has 18 upper and 22 lower teeth; a 200 mm. specimen has 22 upper and 24 lower teeth; a 283 mm. specimen has 24 upper and 26 lower teeth.

TABLE 3

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus bleekeri* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS			ANAL SOFT RAYS	
	24	25	26	23	24
Delagoa Bay, S. Africa		1			1
East Indies		4			4
Philippine Islands	2	5	4	2	9
Tuamotu Archipelago		1			1
Marshall Islands			1		1

Mouth small, its width from rictus to rictus contained 4.7 to 5 in head length; snout short, its length 6.6 to 6.9 in standard length; relative body depth decreasing with size from 2.1 in standard length in 118 mm. specimen to 2.5 in 283 mm. specimen; forehead sloping, the angle between a vertical at the mouth and the anterior profile of the head about 45°; length of head 3.6 to 3.7 in standard length; diameter of eye 3.2 to 4.5 in head length in specimens over a range in standard length of 118 to 283 mm.; caudal concavity about 6.5 to 8 in standard length (9 in a 71 mm. specimen); least depth of caudal peduncle 10 to 12 in standard length. This species has a narrower caudal peduncle than all other species of *Acanthurus* (in which the least depth is contained 7.7 to 9.5 times in the standard length). The stomach is large, **U**-shaped, with about nine rows of very large, thorn-like papillae on the inner surface.

Color (in alcohol) brown with fairly straight lengthwise pale bluish gray lines on the side of the body (28 in a specimen 200 mm. in standard length, each line about one-third as broad as the brown interspaces); head with similar, though slightly more irregular, lines (eight between eye and lower limb of preopercle in the 200 mm. specimen); opercular membranes dark brown; sheath of caudal spine blackish brown and edge of socket dark brown; all fins brown, the dorsal with a dark brown line at the base which becomes broader posteriorly, and the dorsal and the anal with faint longitudinal banding.

Life colors from Hiyama's plate (herein reproduced in black and white as Fig. 7) dark brown with lengthwise blue lines on head and body, a yellow area behind eye, and two yellow bands extending anterior from eye, one from the upper edge and one from the lower.

J. L. B. Smith kindly loaned a specimen identified in his *The sea fishes of southern Africa* (1949: 240, pl. 33, no. 609) as *Acanthurus lineolatus*. The specimen is 71 mm. in standard length and was collected in Delagoa Bay. The species figured by Smith appears to be *A. mata*, however, the specimen turned out to be *A. bleekeri*, hitherto unrecorded from southern Africa. It has been returned to Dr. Smith.

Acanthurus bleekeri is an Indo-West-Pacific species. It is not recorded from the Hawaiian Islands and is not commonly taken from the rest of the tropical Pacific.

Acanthurus thompsoni (Fowler)
Figs. 2*d*, 8

Hepatus thompsoni Fowler (1923: 386) (Honolulu); Fowler and Ball (1925: 19) (Wake Island); Fowler (1928: 268, fig. 49); Fowler (1938: 231) (Honolulu).

Acanthurus philippinus Herre (1927: 434, pl. 5, fig. 1) (Calapan, Mindoro, Philippine Islands); Schultz and Woods *in* Schultz *et al.* (1953: 637) (Rongelap, Marshall Islands); de Beaufort (1951: 161).

Hepatus philippinus Fowler and Bean (1929: 215, fig. 11) (Philippine Islands and East Indies); Kamohara (1952: 8) (Okinoshima, Province of Tosa, Japan).

Teuthis thompsoni Fowler (1949: 102).

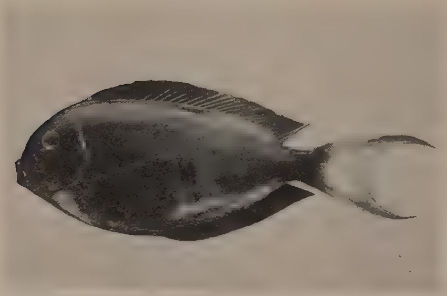


FIG. 8. *Acanthurus thompsoni*. 138 mm. specimen, Gilbert Islands. From a Kodachrome transparency by the author.

Dorsal rays IX, 23 to 26; anal rays III, 23 to 26; pectoral rays 17; anterior gill rakers of two Philippine and one Marshall Islands specimens 15 to 16; posterior gill rakers 14 to 15; anterior gill rakers of one Hawaiian Islands specimen 18; posterior gill rakers 16; a 93 mm. specimen has 20 upper and 24 lower teeth; a 138 mm. specimen has 21 lower and 24 upper teeth.

TABLE 4

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus thompsoni* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS				ANAL SOFT RAYS			
	23	24	25	26	23	24	25	26
East Indies		1		1		1		1
Philippine Islands	2	2	1		1	3	1	
Marshall Islands			1				1	
Gilbert Islands			1			1		
Society Islands			1		1			
Hawaiian Islands		1		2		2		1

Mouth small, its width from rictus to rictus contained about 4 times in head length; snout very short, its length 7.9 to 8.2 in standard length; body depth about 2.3 in standard length; head length 3.7 to 4.3 in standard length; diameter of eye 3.2 to 3.5 in head length in specimens over 90 mm.; least depth of caudal peduncle 2.2 to 2.5 in head length; caudal concavity about 5 in standard length.

Color (in alcohol) brown with pale yellowish brown caudal fin (except specimens from the Hawaiian Islands in which the caudal fin is as dark as the body); a small dark brown spot just below and adjacent to axil of pectoral fin (this spot not as prominent as Fowler figured it and is difficult to see in dark specimens); about six dark bands may be visible running lengthwise in posterior part of soft dorsal fin and about five in the anal fin, although in many specimens these have faded.

Herre (1927: 434) stated that the pale caudal fin of his Philippine specimens was evidently yellow in life; however, the single specimen which I collected in the Gilbert Islands had a snow white caudal fin (which became dusky white immediately following death).

A 134 mm. specimen speared by me at a depth of 90 feet in Kealakekua Bay, Hawaii, was olive drab with brown fins; the dorsal and anal fins had a narrow blue-black margin, and there were two to three narrow longitudinal yellow-brown lines in the outer part of these fins; the pelvic fins showed brownish yellow patches distally; the head had a reticulation of purplish yellow and brownish yellow lines. A 49 mm. juvenile specimen (U.S.N.M. No. 167250) was taken in the same locality and at the same depth. It was apparent from the scale structure and the dentition that it had only recently transformed from the acronurus stage. It was purplish blue with black longitudinal lines on the side of the body; the pectoral was yellowish with a black line at the top; there was a small black spot at the axil of the dorsal fin; however none was visible at the lower part of the axil of the pectoral fin.

I examined the holotype (Bernice P. Bishop Mus. No. 3394) and compared it with the specimen from the Gilbert Islands. Apart from the color of the caudal fin, no differences could be observed.

The largest specimen seen by me is the holotype. It is 155 mm. in standard length.

Schultz and Woods (1953: 637) stated that the species was observed swimming in a large school in the Rongelap lagoon about coral heads at depths of more than 10 feet. I saw only two solitary individuals at Onotoa Atoll in the Gilbert Islands; these occurred at a depth of from 40 to 50 feet on the coralliferous terrace of the outer reef. The adult which was collected in Hawaii was one of a group of about eight or ten individuals that tended to stay in the same general region of the reef. They were seen several times swimming slowly, about 10 to 20 feet off the coral-covered bottom. Upon my approach they swam almost straight down. Underwater some appeared dark gray, almost black, and others were light blue.

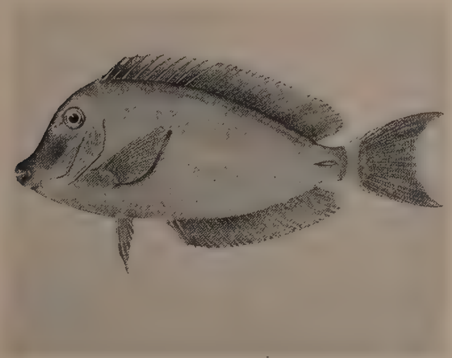


FIG. 9. *Acanthurus mindorensis* (after Herre, 1927).

Acanthurus thompsoni occurs in the East Indies, Philippines, Japan, and Oceania. In general, it is not a common species.

Acanthurus mindorensis Herre
Fig. 9

Acanthurus mindorensis Herre (1927: 433, pl. 4, fig. 2) (Calapan, Mindoro, Philippine Islands).

Hepatus mindorensis Fowler and Bean (1929: 213).

The following is from Herre's description: dorsal rays IX, 26; anal rays III, 23; origin of mouth low on head; jaws protuberant; length of snout 1.25 in length of head (taken from figure); length of head 3.4 in total length; depth at origin of pelvics 2.3 in length; eye 4.16 in head length; interorbital gently rounded, 2.94 in head and nearly thrice eye (one of the last two proportional measurements, probably the latter, is an error); caudal spine slender, its length equal to diameter of eye; depth of caudal peduncle 2.77 in head; caudal fin moderately concave, caudal concavity 11 in standard length (from figure); pectoral fin 1.16 in head; pelvic fin 0.1 as long as head. The type, a 170 mm. specimen, had eight broad denticulate teeth on each side of the upper jaw and eight or nine on each side of the lower jaw. The denticulations on the lower teeth were more confined to the ends of these teeth than were those on the upper teeth. The color (in alcohol) was black,

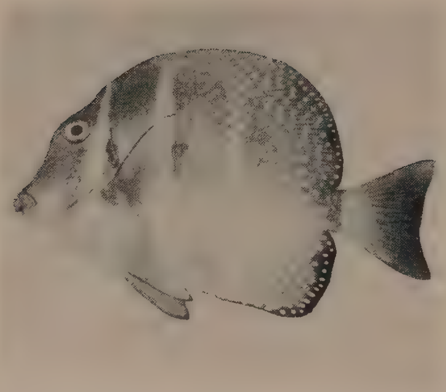


FIG. 10. *Acanthurus guttatus.* 118 mm. specimen, Gilbert Islands. From a Kodachrome transparency by the author.

sides of head and breast blackish brown; a deep brown ring at base of caudal; all fins black.

Herre has informed me that the type of this species was destroyed in Manila during World War II. To my knowledge there are no other specimens in existence.

There are two important differences between Herre's description and his figure, and at the present time there is no way to reconcile these. He described the species as having IX dorsal spines, the first one longer than in most species and not concealed. The figure shows X dorsal spines, the first smaller than that as seen on most of his figures of other species of *Acanthurus*. The deep brown ring at the base of the caudal fin is not apparent in the figure. Instead the base of the caudal fin has a pale band.

The most distinctive feature of this species is the peculiar shape of the head.

Acanthurus guttatus Bloch and Schneider
Figs. 1*j*, 2*e*, 10

Acanthurus Guttatus Bloch and Schneider (1801: xxxviii, 215) (Tahiti).

Acanthurus guttatus Cuvier and Valenciennes (1835: 195) (Tonga Islands and Mauritius); Günther (1861: 329) (Tahiti, New Hebrides, and Mauritius); Günther (1873: 109, pl. 69, fig. A) (Indo-Pacific); Waite (1897: 188) (Funafuti, Ellice Islands); Jordan and Jordan (1922: 66) (Hawaiian Islands); Schultz (1943: 163) (Phoenix and Samoa Islands); de Beaufort (1951: 142) (Sumatra); Schultz and Woods *in* Schultz *et al.* (1953: 631, pl. 66, fig. A) (Marshall and Mariana Islands); Harry (1953: 146) (Raroia, Tuamotu Archipelago).

Harpurus guttatus Forster (1844: 218) (Tahiti).

Rhombotides guttatus Bleeker *in* Bleeker and Pollen (1874: 96) (Réunion and Mauritius).

Zabrasoma guttatus Seale (1901: 110) (Guam).

Teuthis guttatus Jenkins (1903: 479) (Honolulu); Kendall and Goldsborough (1911: 310) (Gilbert Islands and Tuamotu Archipelago); Fowler (1949: 103) (Baker Island).

Hepatus guttatus Jordan and Evermann (1905: 392, fig. 70) (Honolulu); Jordan and Seale (1906: 354) (Samoa); Fowler and Bean (1929: 248) (Philippine Islands, Samoa, Gilbert Islands, and Mauritius); Fowler (1938: 184) (Tongareva).

Teuthis fuliginosus. Whitley and Colefax (1938: 294, pl. 14, fig. 4) (Nauru Island).

Dorsal rays IX, 27 to 30; anal rays III, 23 to 26; pectoral rays 15 to 17; anterior gill rakers 21 to 24; posterior gill rakers 19 to 23 (gill raker counts based on specimens from Samoa); a 43 mm. specimen has eight upper and eight lower teeth; an 85 mm. specimen has ten upper and ten lower teeth; a 152 mm. specimen has 12 upper and 12 lower teeth; a 187 mm. specimen has 12 upper and 14 lower teeth.

Body depth great, 1.5 to 1.6 in standard length; caudal fin slightly emarginate, caudal concavity contained about 14 to 17 times in standard length. Length of pectoral fin about 2.7 in standard length.

Color (in alcohol) brown with many small round or elliptical white spots (usually bordered with dark brown) on posterior half of body and dorsal and anal fins, and three vertical white bars, the first on head just behind eye, the second running from base of fourth dorsal spine to anus, and the third (about one-third as broad) from base of fifth or sixth dorsal soft rays to the second or third anal soft rays; pectoral dusky yellow; pelvics light brown; caudal fin with basal half light brown, outer portion brown.

In life the pelvic fins are bright yellow.

Acanthurus guttatus is characteristic of turbulent water in shallow reef areas. In atolls it is commonly found schooling in surge channels.

The postacronurus may appear in tide pools. Three such specimens (Fig. 1*j*) vary in standard length from 33 to 36 mm.

The largest adult specimen seen by me was 228 mm. in standard length from the Hawaiian Islands.

De Beaufort (1951: 137) is probably in error in considering *Teuthis fuliginosus* Whitley and Colefax a synonym of *Acanthurus fuscus* Steindachner (the latter being a synonym of *Acanthurus pyroferus* Kittlitz). The specimen in Whitley and Colefax's photograph appears to be *A. guttatus* with the white spots barely visible.

Acanthurus guttatus would seem to stand apart from all other species of the genus primarily because of its deep body, nearly truncate caudal fin, and color pattern. *A. leucopareius*, however, appears to link this species with *A. nigrofuscus* and *A. nigroris*, for it is intermediate in body depth, caudal concavity, structure of the teeth, dorsal and anal fin ray counts, size, and color.

TABLE 5
VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus guttatus* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS				ANAL SOFT RAYS			
	27	28	29	30	23	24	25	26
Mauritius	1	1			1	1		
Mariana Islands		2	1	1		2	1	1
Wake Island	2	7	2			7	4	
Marshall Islands	4	11	4		3	8	8	
Gilbert Islands	2	2				2	2	
Samoa Islands	1	7	4	1	2	7	3	1
Phoenix Islands		1				1		
Society Islands	2	3	2		1	2	4	
Tuamotu Archipelago		1	1				1	1
Line Islands	1	1			2			
Hawaiian Islands	1	3		1	1	2	2	

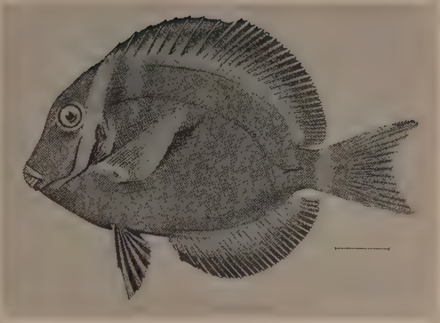


FIG. 11. *Acanthurus leucopareius* (after Jordan and Evermann, 1905).

Acanthurus leucopareius (Jenkins)

Figs. 2*f*, 11

Teuthis leucopareius Jenkins (1903: 476, fig. 23) (Honolulu).

Teuthis umbra Jenkins (1903: 477) (Honolulu); Kendall and Radcliffe (1912: 144) (Cook Bay, Easter Island).

Teuthis bishopi Bryan and Herre (1903: 134) (Marcus Island).

Hepatus leucopareius Jordan and Evermann (1905: 386, fig. 167) (Hawaiian Islands); Jordan and Seale (1906: 352); Fowler (1928: 266, pl. 30, fig. B) (Hawaiian Islands, Easter Island, and Marcus Island); Fowler and Bean (in part) (1929: 214) (Hawaiian Islands and Easter Island).

Hepatus umbra Jordan and Evermann (1905: 387, pl. 47) (Honolulu); Jordan and Seale (1906: 353).

Acanthurus leucopareius Jordan and Jordan (1922: 65) (Honolulu).

Acanthurus umbra Jordan and Jordan (in part) (1922: 65) (Hawaiian Islands).

Dorsal rays IX, 25 to 27; anal rays III, 23 to 25; pectoral rays 16; anterior gill rakers 15 to 18; posterior gill rakers 18 to 21 (raker counts from Hawaiian specimens); a 38 mm. specimen has 8 upper and 10 lower teeth; a 70 mm. specimen has 10 upper and 12 lower teeth; a 109 mm. specimen has 12 upper and 14 lower teeth; a 145 mm. specimen has 14 upper and 16 lower teeth; a 197 mm. specimen has 16 upper and 20 lower teeth.

TABLE 6

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus leucopareius* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS			ANAL SOFT RAYS		
	25	26	27	23	24	25
Hawaiian Islands	6	15	2	3	16	4
Easter Island	1			1		
Marcus Island			1			1

Body depth 1.7 to 1.85 in standard length; caudal concavity 10 to 11 in standard length; length of pectoral fin 2.8 to 3.2 in standard length.

Color (in alcohol) brown with a dusky white band extending from origin of dorsal fin to posterior portion of opercle; posterior and adjacent to this white band a prominent dark brown band; anterior and adjacent to white band an obscure dark brown band which passes through eye; a small black spot at axil of dorsal fin (relatively large in Easter Island specimen); base of caudal fin with a distinct white band; all fins brown except pectorals which are pale with a narrow black upper margin; a faint longitudinal banding may be visible in dorsal and anal fins.

In some specimens the dark and light bands on the head are difficult to see. This is true of some freshly preserved specimens; therefore the lack of bands cannot be attributed solely to fading.

In life the white band on the head and the one at the base of the caudal fin are vivid. Faint irregular bluish lines may be seen on the body. In a 70 mm. specimen the bluish lines are fewer in number and more evident than in large specimens. On the upper one-third of the body they consist of oblique rows of discrete spots.

Transformation from the acronurus to the juvenile stage occurs at a size of about 33 to 34 mm. in standard length. The dark and light bands on the head are just making their appearance on a 40 mm. specimen.

I examined the type of *Teuthis bishopi* Bryan and Herre at the Bishop Museum (a 206 mm. specimen from Marcus Island) and the type of *Teuthis umbra* Jenkins at the United States National Museum; both are specimens of *Acanthurus leucopareius*. As the bands on the head of the type of *umbra* are very faint, it is understandable how Jenkins could have overlooked them and considered the specimen as representing a new species.

Since Jenkins, a number of authors have applied the name *umbra* to various species of *Acanthurus*. Of the specimens considered as *Acanthurus umbra* by Jordan and Jordan (1922), for example, some were *A. mata*, one was *A. xanthopterus*, and one was *A. leucopareius*. *A. mata* received the designation of *umbra* more than other species probably because of its marked pale band at the base of the caudal fin and lack of other obvious color markings.

Fowler (1928: 266) listed two "Albatross" specimens from Puako Bay, Hawaii (U.S.N.M. No. 55582), as *Hepatus leucopareius*. One of these, however, is either *Acanthurus xanthopterus* or *A. mata*. The two which he recorded as *leucopareius* from Apia, Samoa (U.S.N.M. No. 52456) are *Acanthurus nigroris*, as is the one from the Tubuai Islands (Bishop Mus. No. 750). The 105 mm. specimen from Suva, Fiji (Bishop Mus. No. 4339), which was identified as *Hepatus leucopareius*, is *Acanthurus mata*. Also misidentified by Fowler as *leucopareius* are two subadults from the New

Hebrides (Bishop Mus. No. 1028). Two specimens from Guam (Bishop Mus. No. 4261) which Fowler (1925: 12) reported as *Hepatus leucopareius* are 26 mm. acronuri which are definitely not this species.

Fowler (1930: 612) recorded *Hepatus leucopareius* from Hong Kong. I was unable to locate his specimen at the Academy of Natural Sciences of Philadelphia. Also I have not examined his specimens of *leucopareius* from the Philippines. His reference to their poor condition (1927*a:* 287) suggests that this may be a tenuous identification. A. W. Herre has written me that he has never seen *Acanthurus leucopareius* in the Philippines. The presence of the species in his checklist (1953: 536) is probably based on Fowler.

The only definite records of this species are from the Hawaiian Islands, Marcus Island, and Easter Island, all remote and widely separated areas of Oceania. If these three regions represent the total distribution, *A. leucopareius* would seem to be a relict species. It is easier to suppose that it was once in continuous distribution throughout Oceania but survives now only in these three outposts than to assume that it is endemic to one of these islands and spread to the others without becoming established in intervening areas.

This species is one of the most common of the genus in the Hawaiian Islands. It is most often seen in relatively shallow reef areas subject to some turbulence from wave action. It has been observed in schools.

Acanthurus nigroris Cuvier and Valenciennes

Figs. 1*i*, 2*g*, 12

Acanthurus nigroris Cuvier and Valenciennes (1835: 208) (Hawaii); Weber (1913: 317) (East Indies).

Acanthurus lineolatus. Bleeker (1854*a:* 101) (Banda Islands, East Indies); Günther (1873: 112, pl. 73, fig. A) (Society Islands); Steindachner (1901: 493) (Honolulu); de Beaufort (in part ?) (1951: 160) (East Indies).

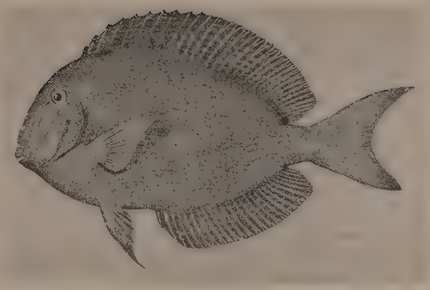


FIG. 12. *Acanthurus nigroris* (after Jordan and Evermann, 1905, retouched).

Acanthurus bipunctatus Günther (1861: 331) (China).

Acanthurus nigros Günther (1861: 332) (New Hebrides); Günther (in part) (1873: 110) (New Hebrides, Palau Islands, and Tahiti).

Rhombotides lineolatus. Bleeker (1865: 288) (Ambon, East Indies).

Teuthis atrimentatus Jordan and Evermann (1903: 198) (Honolulu); Jenkins (1903: 478) (Hawaiian Islands).

Teuthis striatus. Bryan and Herre (1903: 133) (Marcus Island).

Hepatus atramentatus Jordan and Evermann (1905: 393, fig. 171) (Hawaiian Islands); Jordan and Seale (1906: 352) (Samoa).

Acanthurus atramentatus Jordan and Jordan (1922: 65) (Hawaiian Islands); Herre (1927: 422, pl. 3, fig. 1) (Philippine Islands).

Hepatus elongatus. Fowler (in part) (1928: 267) (Oceania).

Hepatus lineolatus. Fowler (in part) (1928: 270) (Oceania); Fowler and Bean (in part) (1929: 228) (Philippine Islands and Hawaiian Islands); Fowler (1931: 345) (Honolulu); Fowler (1938: 232) (Honolulu).

Hepatus fuliginosus. Fowler and Bean (in part) (1929: 211) (Honolulu).

Hepatus leucopareius. Fowler and Bean (in part) (1929: 214) (Apia, Samoa).

Teuthis lineolatus. Fowler (1941: 257, fig. 9) (Honolulu); Fowler (1949: 103) (Howland Island).

Acanthurus elongatus. Schultz (in part) (1943:

165) (Phoenix and Samoa Islands); Schultz and Woods *in* Schultz *et al*. (in part) (1953: 634, pl. 62, fig. C) (Marshall and Mariana Islands).

Dorsal rays IX, 23 to 27; anal rays III, 22 to 25 (one specimen from the Hawaiian Islands has IV anal spines); pectoral rays 15 or 16; a 61 mm. specimen has 10 upper and 12 lower teeth; a 96 mm. specimen has 12 upper and 14 lower teeth; a 159 mm. specimen has 12 upper and 14 lower teeth. See Table 9 for gill raker counts.

TABLE 7

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus nigroris* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS					ANAL SOFT RAYS			
	23	24	25	26	27	22	23	24	25
Marshall Islands		21	18			13	19	7	
Gilbert Islands		2	1			2	1		
Rose Island, Samoa Is.		4	7				8	3	
Swains Island, Samoa Is.	1	3	3			2	5		
Phoenix Islands	2	12	7	1		3	17	2	
Line Islands		1	2			1	2		
Wake Island		4	7	1			10	2	
Oahu and Hawaii		1	7	20	2		4	14	12
Laysan and French Frigate Shoal			2	6			1	3	4
Johnston Island		3	8	9		1	6	10	3

Caudal concavity 5.8 to 10.5 in standard length (5.8 to 7.5 in specimens from the Hawaiian Islands and Johnston Island and 6.7 to 10.5 from elsewhere in the Pacific); body depth 1.8 to 2 in standard length; ends of central upper teeth rounded (Fig. 2*g*).

The largest specimen seen by me measures 204 mm. in standard length. It was collected at French Frigate Shoal.

Color (in alcohol) of Hawaiian specimens brown with irregular, lengthwise, bluish gray or dark brown lines (about one-fourth as broad as intervening brown areas) on body; about six or seven slightly irregular, narrow, dark bluish gray or dark brown lines on head running parallel to profile of snout (in some preserved specimens these lines and those on the body are very faint or imperceptible); a small black spot about the size of the pupil at the axil of both the dorsal and the anal fins; dorsal fin with about five or six lengthwise dark brown bands; anal fin with four or five similar bands; a light grayish brown band often present at base of caudal fin; posterior margin of caudal fin very narrowly pale; pectoral fin pale with narrow dark upper margin; pelvic fins brown; no narrow black margin around socket of caudal spine.

In life the bluish gray or dark brown lines on the body and head are light blue; the dark bands in the dorsal and anal fins are bluish and the intervening bands light yellowish brown; pectoral fin rays dull yellow, membranes clear; iris yellow.

Wake Island specimens, even large adults, have rows of small round blue spots on the body instead of entire or slightly broken blue lines. Specimens from elsewhere in Oceania appear to be colored much like Hawaiian examples, as indicated in the color plate in Günther (1873) of a specimen from the Society Islands (identified as *Acanthurus lineolatus*).

The number of blue lines on the body are fewer in smaller specimens. A 51 mm. juvenile from the Hawaiian Islands, for example, has only 11 lines on the body.

In this species and *Acanthurus nigrofuscus* the black spot in the axil of the dorsal fin makes its appearance before the spot in the axil of the anal fin. The dorsal spot first shows before these species complete the transformation from the acronurus to the juvenile state (which occurs at a standard length of from about 34 to 39 mm. in *A. nigroris*). The anal spot first appears on specimens of *nigroris* about 42 to 50 mm. in standard length.

A. nigrofuscus seems to be closely related to *A. nigroris*, and these two species have often been confused. As indicated in the key, they may be separated by caudal concavity, body depth, maximum size, shape of upper teeth, size of the spot in the axil of the dorsal fin, width of the pale posterior margin of the caudal fin, presence or absence of spots on the head, and presence or absence of a dark margin around the groove of the caudal spine. In addition, the posterior tips of the dorsal and anal fins of *A. nigrofuscus* are more pointed when these fins are elevated than are the fins of *A. nigroris*. The base of the caudal fin of *A. nigrofuscus* is rarely paler than the rest of the fin or the body. The bands in the dorsal and anal fins of *A. nigrofuscus* are poorly defined and rarely persist in preserved specimens. The lips of *A. nigrofuscus* tend to be blackish while those of *A. nigroris* are usually only slightly darker than the rest of the head.

Small juveniles of these two species are difficult to distinguish, but the greater concavity of the caudal fin and larger black spot at the base of the last few dorsal and anal rays of *A. nigrofuscus* still permit separation. I am unable, however, to distinguish with assurance the acronurus or postacronurus larval forms of these species. The immediate postacronurus of Figure 1*i* from Wake Island is identified largely because of the prevalence of *A. nigroris* at this island and the apparent absence of *A. nigrofuscus* (as based on collections and observations of W. A. Gosline and the author).

The Phoenix Islands, Swains Island, and Johnston Island are other areas in the Pacific from which *A. nigroris* has been taken and *A. nigrofuscus* is as yet unknown. Forty-seven specimens of *A. nigroris* were collected by L. P. Schultz from the Phoenix Islands and Swains Island. These are not as well differentiated from *A. nigrofuscus* as specimens from other regions such as the Marshall Islands. The caudal fin is slightly more lunate, and the white posterior edge is broader; the black spots at the rear base of the dorsal and anal fins are a little larger. Forty-eight specimens of *A. nigroris* were collected by Gosline, Brock, Yamaguchi, *et al.* from Johnston Island. Also there are several specimens of this species from Johnston in the United States National Museum and the Bishop Museum. When *A. nigroris* and *A. nigrofuscus* occur together, the latter is usually more prevalent. For example, the 82 specimens of these two species collected by Schultz at Rose Island in the Samoa Islands include only eight *A. nigroris*.

The populations of *A. nigroris* from Johnston Island and the Hawaiian Islands differ significantly from those of other regions of the Pacific in having higher fin ray counts (Table 7), higher gill raker counts (Table 9), and more concave caudal fins. There appear to be slight meristic differences between the species in Johnston Island and the Hawaiian Islands.

The type of *Acanthurus nigroris* Cuvier and Valenciennes is in the Paris Museum. The type locality is Hawaii. According to L. Bertin (personal communication), the specimen is 130 mm. in standard length and has 12 upper and 12 lower teeth (Cuvier and Valenciennes recorded 12 upper and 14 lower teeth). Of the known species of Hawaiian acanthurids, this information alone narrows the possibility to three, *A. nigroris* as here defined, *A. nigrofuscus*, and *A. leucopareius*. Apparently no color markings are now evident on the specimen, but information on the shape of the caudal fin and ends of the dorsal and anal fins clearly eliminates *A. nigrofuscus*. Failure of Cuvier and Valenciennes to mention the vertical white and dark brown bands on the head, so characteristic of *A. leucopareius*, strongly favors the present use of the name *nigroris*.

Jordan and Evermann (1903) were the first to realize that the use of the name *lineolatus* for this species was an error. They proposed the name *atramentatus*. I examined their type of *Teuthis atramentatus* (= *Acanthurus nigroris*) in the United States National Museum.

Through correspondence with A. C. Wheeler of the British Museum, I was able to learn that one of the types of *Acanthurus bipunctatus* Günther is *A. nigroris* and the other is *A. nigrofuscus*. Günther also included specimens of both of these species as types of *Acanthurus nigros*. For purposes of synonymy I designate as the lectotype of *Acanthurus bipunctatus* Günther the 126 mm. specimen (British Mus. No. 1848.3.13.215) from China. I designate as lectotype of *Acanthurus nigros* Günther the 160 mm. specimen (British Mus. No. 1861.5.31.29) from the New Hebrides. Thus both of these names become synonyms of *Acanthurus nigroris* Cuvier and Valenciennes as the species in here interpreted.

A. nigroris appears to range throughout Oceania. The species probably occurs in China, the Philippines, and the East Indies as well. I have seen no specimens from the Indo-Malayan region. Herre's (1927: 422) description of *Acanthurus atramentatus* (Jordan and Evermann) from the Philippines seems to apply to *A. nigroris;* however his figure (pl. 3, fig. 1) is suggestive of *A. nigrofuscus*. Bleeker's (1854*a:* 101) description of *Acanthurus lineolatus* (not of Cuvier and Valenciennes) from the Banda Islands, East Indies, and that of de Beaufort (1951: 160) check with *A. nigroris*. De Beaufort's reference to a lunate caudal fin and certain variability in color pattern suggests, however, that he also had some specimens of *A. nigrofuscus*.

Acanthurus nigrofuscus (Forskål)
Fig. 2*h*, Pl. 1

Chaetodon nigro-fuscus Forskål (1775: xiii, 64) (Red Sea).

Chaetodon nigrofuscus Linnaeus and Gmelin (1788: 1268).

Acanthurus rubropunctatus Rüppell (1828: 59, pl. 15, fig. 1) (Red Sea); Günther (1861: 333); Klunzinger (1871: 508) (Red Sea).

Acanthurus matoides Cuvier and Valenciennes (1835: 204) (Oualan).

? *Acanthurus lineolatus* Cuvier and Valenciennes (1835: 207) (East Indies).

Acanthurus nigro-fuscus Cuvier and Valenciennes (1835: 214) (Réunion and Red Sea).

Acanthurus rubro-punctatus Cuvier and Valenciennes (1835: 222).

Ctenodon rubropunctatus Swainson (1839: 256).

Acanthurus mata. Day (1876: 205, pl. 48, fig. 1) (seas of India).

Acanthurus (*Rhombotides*) *nigrofuscus* Klunzinger (1884: 84) (Red Sea).

Acanthurus gahm. Day (1888: 789) (*mata* of Day, 1876); Day (1889: 141).

Acanthurus bipunctatus. Steindachner (1901: 494) (Honolulu).

Teuthis bipunctatus. Jordan and Evermann (1902: 358) (Kotosho Island, Formosa); Jordan and Fowler (1902: 554) (Riu Kiu Islands and Formosa); Jenkins (1903: 479) (Honolulu).

Hepatus elongatus. Jordan and Evermann (1905: 389) (Hawaiian Islands); Jordan and Seale (1906: 352) (Samoa); Fowler (in part) (1928: 267) (Oceania); Fowler and Bean (in part) (1929: 213) (Hawaiian Islands); Fowler (1938: 230) (Honolulu); Aoyagi (1943: 208, pl. 6, fig. 18) (Riu Kiu Islands); Kamohara (1954: 52, fig. 13) (Tokara Islands, southern Japan).

Acanthurus elongatus. Jordan and Jordan (1922: 65) (Hawaiian Islands); Herre (1936: 246) (Tuamotu Archipelago and New Hebrides); Schultz (in part) (1943: 165) (Samoa Islands); Schultz and Woods *in* Schultz *et al.* (1953: 634, pl. 62, fig. D) (Marshall and Mariana Islands); Harry (1953: 148) (Raroia, Tuamotu Archipelago).

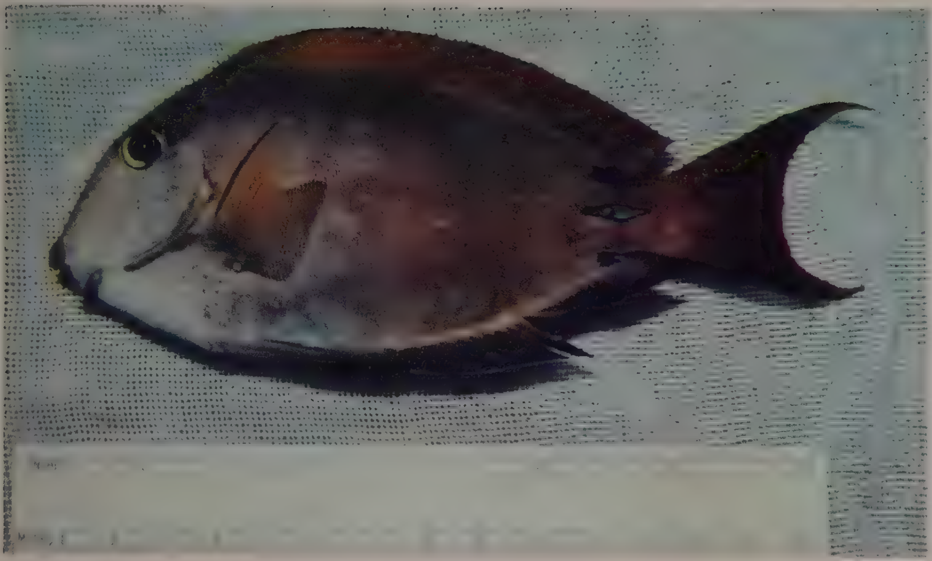
Teuthis elongatus. Barnard (1927: 778) (Natal coast, Africa).

Acanthurus marginatus. Herre (1927: 427, pl. 3, fig. 2) (Philippine Islands).

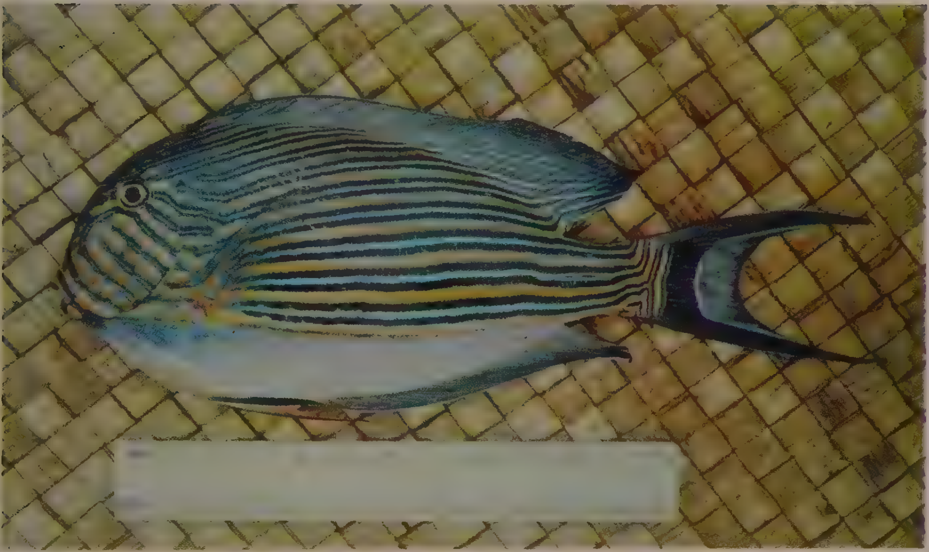
Acanthurus nigroris. Herre (1927: 428, pl. 4, fig. 1) (Philippine Islands and Guam); Schmidt (1930*b:* 103) (Riu Kiu Islands).

Hepatus fuliginosus. Fowler (in part) (1928: 266) (Oceania).

Hepatus lineolatus. Fowler (in part) (1928: 270) (Oceania); Fowler and Bean (in part) (1929: 228) (Philippine Islands, Mauritius, Samoa, and Hawaiian Islands); Pietschmann (1938: 26, pl. 2, fig. C) (Molokai, Hawaiian Islands).



Acanthurus nigrofuscus, Hawaiian Islands.



Acanthurus lineatus, Gilbert Islands.

Acanthurus flavoguttatus. Herre (1936: 245) (New Hebrides).

Hepatus lucillae Fowler (1938: 231, fig. 23) (Honolulu).

Teuthis lucillae Fowler (1941: 257) (Honolulu); Fowler (1949: 103).

Dorsal rays IX, 24 to 27; anal rays III, 22 to 24; pectoral rays 16 or 17; a 55 mm. specimen has 10 upper and 12 lower teeth; a 79 mm. specimen has 12 upper and 14 lower teeth; a 120 mm. specimen has 12 upper and 14 lower teeth; a 148 mm. specimen has 14 upper and 16 lower teeth. See Table 9 for gill raker counts.

TABLE 8

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus nigrofuscus* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS				ANAL SOFT RAYS		
	24	25	26	27	22	23	24
Red Sea	4				2	2	
Mauritius	1	4				2	3
East Indies		1	1			1	1
Philippine Islands	2	2	1			4	1
Okinawa		1				1	
Mariana Islands	2	8			1	6	3
Marshall Islands	15	24	2			29	12
Gilbert Islands	2		1		1	1	1
Palau Islands		2	1			1	2
Samoa Islands	14	18	7	1	1	22	17
Hawaiian Islands	6	16	4		1	9	16

Caudal fin lunate, caudal concavity 4.5 to 6 in standard length; body depth 2 to 2.3 in standard length; ends of upper teeth tend to be pointed (Fig. 2*h*).

Color (in alcohol) brown, with or without fine bluish gray longitudinal lines on body; a prominent black spot, greater in width than half the diameter of eye, in axil of dorsal fin; a slightly smaller black spot in axil of anal fin; head and chest in life with numerous small bright orange spots which may or may not persist as pale spots in preservative; caudal fin with a distinct dull white posterior border, about one-half pupil diameter in width at the center and becoming narrow out on lobes (in East Indian and Indian Ocean specimens this border is narrower); an indistinct blackish brown area submarginal to white border of caudal fin; a narrow black margin around socket of caudal spine; lips blackish brown; dorsal and anal fins with faint longitudinal banding in life which is rarely evident on preserved specimens; margin of dorsal and anal fins narrowly dark (blue in life on anal fin); pectoral fin pale with upper edge narrowly black; pelvic fins brown.

Acanthurus nigrofuscus appears to reach a larger size in the Hawaiian Islands than in the Marshall, Mariana, and Samoa Islands (island groups from which large collections of this species are available). In Hawaii the species attains a size of at least 152 mm. in standard length. Few specimens from the Marshalls, Marianas, or Samoa exceed 100 mm. in standard length. One 143-millimeter-long specimen was found in a collection from Mauritius.

Although the acronurus is difficult to separate from that of *A. nigroris*, late transforming specimens of *A. nigrofuscus* have been identified from the Hawaiian Islands and the Marshall Islands. The size at transformation in both areas is about 43 mm. A 34 mm. postacronurus from the East Indies is identified as this species.

I know of no type material of *Acanthurus nigrofuscus* (Forskål). The species was described as having a brown-black body and a caudal fin with a whitish posterior edge and lobes which are falcate and half as long as the entire fin. Although the description of *A. nigrofuscus* is brief, it fits the species as here defined better than any other known species of the genus. This is especially true when only the species of *Acanthurus* in the Red Sea and their relative abundance are considered. With the possible exception of *A. sohal* (Forskål) and *A. gahhm* (Forskål), *A. nigrofuscus* appears to be the most common species of the genus in the Red Sea. Although Forskål did not

TABLE 9
VARIATION IN GILL RAKER COUNTS OF SPECIMENS OF *Acanthurus nigroris* AND *Acanthurus nigrofuscus* FROM DIFFERENT LOCALITIES

SPECIES AND LOCALITY	ANTERIOR GILL RAKERS												POSTERIOR GILL RAKERS									
	20	21	22	23	24	25	26	27	28	29	30	31	18	19	20	21	22	23	24	25	26	27
A. nigroris																						
Marshall Islands		1	2	2	3	2									3	1	3	2	1			
Phoenix Islands		1	2	4	3	1									2	3	3	2	1			
Samoa Islands		1	2	1	3	3								1	2	2	3	2				
Wake Island			1	3	3										2	1	2	1	1			
Hawaiian Islands							1	3	3	2	1							1	3	4	2	
Johnston Island							2	2	3	2		1							2	2	4	2
A. nigrofuscus																						
Marshall Islands	2	2	5	1									2	3	3	2						
Samoa Islands	1	2	5	2	1								1	2	4	3		1				
Hawaiian Islands		2	3	3	2									3	3	3	1					

state that a black spot was present at the axil of the dorsal and anal fins, these spots could have been overlooked. Specimens of *A. nigrofuscus* in the United States National Museum recently collected from the Red Sea are sufficiently melanistic so that these spots cannot be perceived easily without holding the fish in front of a bright light.

The failure to note these spots by some authors and their observance by others has contributed to the nomenclatorial confusion of this species. More confusing is the evanescent quality of the orange spots on the head. A number of synonyms of *A. nigrofuscus* owe their origin to descriptions from fresh specimens on which the spots are the most conspicuous color feature. Preserved specimens, with these spots faint or absent, have often been listed under different names. Rüppell (1828: 59, pl. 15, fig. 1) described and figured *Acanthurus rubropunctatus* from the Red Sea. He emphasized the small red spots on the head, but did not mention black spots in the axils of the dorsal and anal fins. W. Klausewitz (personal communication) has provided additional information on the types in the Senckenberg Museum at Frankfurt. These have a black spot at the base of the last few dorsal rays and another at the base of the last few anal rays.

I have examined the holotype and paratypes of *Hepatus lucillae* Fowler at the Academy of Natural Sciences of Philadelphia. The specimens are *Acanthurus nigrofuscus*. They were considered distinctive by Fowler largely because of the bright golden spots on the head.

Herre, in his review of Philippine surgeon fishes (1927), listed this species under two names, *Acanthurus marginatus* Cuvier and Valenciennes (with whitish spots on the head) and *Acanthurus nigroris* Cuvier and Valenciennes. The former is a new name for *Acanthurus guttatus* Kittlitz. I was unable to locate Kittlitz' type; it was described as a brown fish with numerous blue spots on the head and body and is either the true *Acanthurus nigroris* or a *Ctenochaetus* (see Randall, in press, *a*). In 1936 Herre used two different names for *A. nigrofuscus;* these were *Acanthurus flavoguttatus* Kittlitz [probably = *Ctenochaetus striatus* (Quoy and Gaimard)] and *Acanthurus elongatus* (Lacépède).

The name *elongatus* has been applied to the species *Acanthurus nigrofuscus* by other authors as well. Not only is *Chaetodon elongatus* Lacépède a later name than *Chaetodon nigrofuscus* Forskål, but it was used by Lacépède for another species, probably one in the *A. xanthopterus–A. mata–A. dussumieri* complex.

L. Bertin has supplied me with sufficient information on the type of *Acanthurus matoides* Cuvier and Valenciennes to enable me to place this name in the synonymy of *Acanthurus nigrofuscus*. The type of *A. matoides* is 120 mm. in standard length, has 12 upper and 12 lower teeth, and a caudal concavity of 23 mm. This name has been most commonly used for the species *Acanthurus xanthopterus* Cuvier and Valenciennes.

Bertin could find no type of *Acanthurus lineolatus* Cuvier and Valenciennes in the Paris Museum. The original description is too brief to permit certain identification. Mention of the shape of the caudal fin and of fine longitudinal blue lines on the body suggests that these authors had specimens of *Acanthurus nigrofuscus*.

Acanthurus lineatus (Linnaeus)

Figs. 1*e*, 2*i*, Pl. 1

Chaetodon lineatus Linnaeus (1758: 274) (Indies).

Acanthurus Lineatus Bloch and Schneider (1801: xxxviii, 214) (East Indies).

Acanthurus lineatus Lacépède (1802: 547, 550); Cuvier and Valenciennes (1835: 223) (East Indies); Bleeker (1853*a:* 263) (Sumatra); Günther (1861: 333) (East Indies and Philippine Islands); Kner (1865–67: 210) (Tahiti); Günther (1873: 111, pl. 70) (East Indies, Polynesia south of equator, and Indian Ocean); Day (1876: 203) (seas of India); Day (1889: 138); Weber (1913: 317) (East Indies); Herre (1927: 420, pl. 14, fig. 1) (Philippine Islands and Guam); Herre (1936: 242) (Bora Bora and New Hebrides); Schultz (1943: 165) (Phoenix and Samoa Islands); Smith (1949: 240, pl. 33, no. 610) (east coast of Africa south to Delagoa Bay); de Beaufort (1951: 147) (East Indies); Schultz and Woods *in* Schultz *et al.* (1953: 630) (Marshall and Mariana Islands); Harry (1953: 149) (Raroia, Tuamotu Archipelago).

Acanthurus vittatus Bennett, J. W. (1828: pl. 2) (Ceylon).

Ctenodon lineatus Swainson (1839: 256).

Harpurus lineatus Forster (1844: 216).

Rhombotides lineatus Bleeker (1863: 235) (Ternate, East Indies).

Teuthis lineatus Seale (1901: 108) (Guam); Schmidt (1930*a:* 555) (Riu Kiu Islands); Fowler (1946: 198) (Riu Kiu Islands); Fowler (1949: 102) (Jarvis Island and Howland Island).

Hepatus lineatus Jordan and Seale (1906: 351) (Samoa); Evermann and Seale (1923: 78) (Guadalcanal, Solomon Islands); Fowler (1928: 269) (Oceania); Fowler and Bean (1929: 218, fig. 12) (Philippine Islands and East Indies); Fowler (1938: 147, 202) (Tahiti and Christmas Island); Aoyagi (1943: 215, pl. 6, fig. 17) (Riu Kiu Islands).

Dorsal rays IX, 27 to 30; anal rays III, 25 to 28; pectoral rays 16; anterior gill rakers 14 to 16; posterior gill rakers 13 to 15 (raker counts from Samoan specimens); a 107 mm. specimen has 12 upper and 14 lower teeth; a 180 mm. specimen has 14 upper and 15 lower teeth.

TABLE 10

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus lineatus* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS				ANAL SOFT RAYS			
	27	28	29	30	25	26	27	28
Mauritius.	1					1		
East Indies.		1					1	
Palau Islands.	1	4	2				6	1
New Hebrides. . . .	1	1			1	1		
Philippine Islands	1	1					2	
Mariana Islands. . .	5	9	3			1	10	6
Marshall Islands. .	3	6				3	6	
Gilbert Islands. . .	5	3				2	4	2
Samoa Islands. . . .	5	2	1			2	5	1
Society Islands. . .	4	4				3	5	
Marquesas Islands				1				1

Caudal fin strongly lunate, caudal concavity contained 3.3 to 4.5 times in standard length; caudal spine long (its length about

1.9 to 2 in head length), slender, and sharp on both edges; body depth 2.1 to 3 in standard length (in specimens over 100 mm. in standard length).

Color in alcohol: lower one-fourth of body light grayish brown; upper three-fourths with alternate pale yellowish white and broad black near-longitudinal lines, each of the latter bissected with a pale bluish gray line; head with a varying pattern of curved lines similar to those on body (but with black lines narrower); dorsal fin with numerous alternating narrow dark brown and bluish gray lines; anal fin dusky yellow; both dorsal and anal fins with a narrow black margin (extreme edge pale); caudal fin dark brown with vertical dark and light lines at base and a large crescentic area in mid-posterior portion; pectoral fin pale with dusky rays; pelvic fins light yellowish brown, the outer margin black.

Fowler and Bean (1929: fig. 12) demonstrated the variability in color pattern which may be seen in Philippine specimens of this species. The two sides of the same fish may show different patterns of lines.

In addition to the blue, yellow, and black color as seen in adults, four juvenile specimens (37 to 40 mm. in standard length) from the Gilbert Islands displayed bright red color on the dorsal and anal fins (especially posteriorly) and on the caudal fin and pelvic fins.

Four specimens examined from the Marianas, Palaus, and East Indies are in the stage of transformation from the acronurus to the juvenile state at a size of from 27 to 32.5 mm. in standard length.

Museum specimens of transforming *A. nigroris* have been found misidentified as *A. lineatus*. Although both have a linear color pattern in the late acronurus (Fig. 1*e* and *i*), they may be distinguished readily.

Acanthurus lineatus is distributed from East Africa to the central Pacific. It appears to be absent from the Red Sea. It is not known from the Hawaiian Islands, Johnston Island, Wake Island, or Marcus Island (Fowler, 1928: 269, was in error in considering *Teuthis striatus* Bryan and Herre to be *A. lineatus;* the specimens are *A. nigroris*). The extensive collections of fishes from the northern Marshall Islands, which are being reported on by Schultz *et al.* (1953), include only two specimens of this species. In the Gilbert Islands, however, I found *A. lineatus* to be very common, especially in the surge channel habitat. Vernon E. Brock has informed me that the species is common at Palmyra in the Line Islands.

The colorful *A. lineatus* and *A. sohal* are well demarked from other species of *Acanthurus*. They are distinctive in the possession of dark lengthwise bands on the body, strongly lunate caudal fins, and highly developed caudal spines. In addition to being very long and sharp, the spines of these two species are peculiar in being nearly free of sheath.

Acanthurus sohal (Forskål)
Figs. 1*g*, 2*j*, 13

Chaetodon sohal Forskål (1775: xiii, 63) (Red Sea).

Chaetodon Sohar Linnaeus and Gmelin (1788: 1268) (coasts of Arabia).

Acanthurus Sohal Bloch and Schneider (1801: xxxviii, 215) (coasts of Arabia); Cuvier and Valenciennes (1835: 227) (Red Sea).

Acanthurus carinatus Bloch and Schneider (1802: 216) (Arabian Sea).

Aspisurus sohar Lacépède (1802: 556) (sea of Arabia).

Choetodon sohab Cuvier (1817: 331) (after Linnaeus and Gmelin).

Acanthurus sohal Rüppell (1828: 56, pl. 16, fig. 1) (Red Sea); Günther (1861: 334) (Red Sea); Klunzinger (1871: 507) (Red Sea).

Ctenodon Rüppelii Swainson (1839: 256, fig. 74).

Acanthurus (*Rhombotides*) *sohal* Klunzinger (1884: 83) (Red Sea).

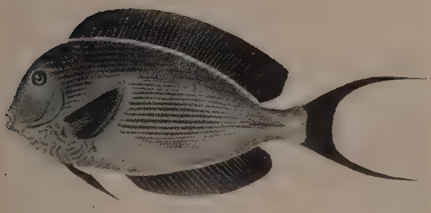


FIG. 13. *Acanthurus sohal* (after Rüppell, 1828).

Dorsal rays VIII, 30 or 31; anal rays III, 28 or 29 (usually 29); pectoral rays 17 (fin ray counts from six specimens from the Red Sea); anterior gill rakers 15 to 17; posterior gill rakers 14 or 15 (raker counts from three Red Sea specimens); an 87 mm. specimen has 12 upper and 14 lower teeth; a 130 mm. specimen has 12 upper and 16 lower teeth; a 206 mm. specimen has 14 upper and 16 lower teeth; a 270 mm. specimen has 16 upper and 18 lower teeth.

Caudal fin strongly lunate, caudal concavity contained about 3 to 4 times in standard length (in specimens over 150 mm. in standard length; an 87 mm. specimen has a caudal concavity which is contained 5 times in its standard length); caudal spine long in adults (1.9 to 2 in head length), slender, very sharp, and without a thick sheath; body depth 2 to 2.2 in standard length; diameter of eye varies from 3 in head length of 87 mm. specimen to 5 in head length of 270 mm. specimen.

Color (in alcohol) light brown with about 15 longitudinal dark brown bands (each about two to three times as broad as intervening light brown bands) on side of body above level of lower part of pectoral fin; on the back a second less conspicuous and more oblique series of bands which become relatively narrower with age; longitudinal dark lines on head dorsal to lower margin of eye; dorsal, anal, and pelvic fins brownish black (smaller specimens with lengthwise bands in dorsal fin); caudal fin black, shading to dark brown in center, with a narrow pale margin (broader in smaller specimens); pectoral fin dark brown, slightly paler in upper middle portion, with narrow pale posterior margin; caudal spine and margin of socket cream.

Color of a fresh specimen as shown in a photograph (Cousteau, 1952: 461): body below pectoral fin light tan, above with alternating dark brown and pale bluish bands; caudal spine bright orange; dorsal and anal fins black with a narrow blue line at the base which becomes broader posteriorly; anal fin with a narrow blue margin; caudal fin dark brown, shading to black peripherally except narrow margin which is blue; pectoral fin light brown on upper half, dusky blue on lower half, with a black margin all around fin; pelvic fins black with narrow blue margin.

Although this species reaches a large size (at least 270 mm. in standard length), it has a small acronurus. The transforming specimen shown in Figure 1*g* is 21 mm. in standard length.

Acanthurus sohal appears to be confined to the Red Sea.

Al=Hussaini (1947: 40, fig. 10) described the anatomy of the alimentary tract of this species. He stated that it feeds on various kinds of algae, but ingests large amounts of *Sargassum*. I examined the gut content of a 122 mm. specimen; it consisted primarily of fine filamentous green algae.

Fowler and Bean (1929: 216) erroneously applied the name *sohal* to the species *Acanthurus tennenti* Günther.

Acanthurus leucocheilus Herre
Fig. 14

Acanthurus leucocheilus Herre (1927: 419, pl. 12, fig. 3) (Philippine Islands); de Beaufort (1951: 140).

The following is based on Herre's description of three specimens, 175 to 200 mm. long, from Bantayan Island, and a 196 mm. spec-

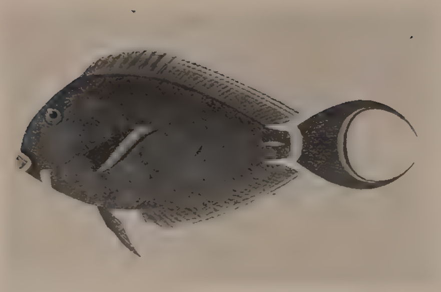


FIG. 14. *Acanthurus leucocheilus* (after Herre, 1927).

imen from Cebu: dorsal rays IX, 24 or 25; anal rays III, 23; 9 or 10 teeth with broad lobate tips on each side of upper jaw and 10 or 11 on each side of lower jaw; depth of body 2 to 2.4 in length; head 3.3 to 3.7 in length; snout 1.3 to 1.44 in head; eye 3.6 to 3.9 in head; eye 1.07 to 1.28 in interorbital; caudal deeply lunate with long pointed tips (caudal concavity in figure about 3.5 in standard length); length of pectoral approximately equal to length of head; first ventral ray elongate, 1.1 to 1.25 in head. Color (in alcohol) blackish brown; snout just above and behind lips black; a bluish white band encircling mouth (though it may be only partially developed on upper lip); a similar but wider white band across chest; a broad bluish white band around base of caudal; pectoral black with a white bar on posterior third; dorsal, anal, and pelvic fins black or brownish black; caudal fin black, sometimes with a bluish white lunate band near posterior margin; caudal spine white, its groove with a narrow black margin. A fresh specimen, 186 mm. in length, from Agutaya, one of the Cuyo Islands, was blackish brown above, deep brown elsewhere except cheeks and snout which were reddish brown; lips reddish with a bluish band around mouth; the chest band was bluish white; soft dorsal fin with three and anal fin with two dark red lines near margin alternating with bluish; narrow margin of these fins sky blue, posteriorly brick red; caudal fin very dark brown with a wide bluish white band around base and a submarginal blue band posteriorly; pectoral blackish brown with a bright yellow bar on posterior third, the margin with rays dusky, membranes clear; pelvics black basally and along outer margin, the rest brick red.

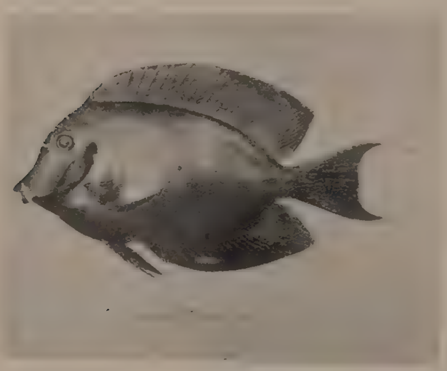


FIG. 15. *Acanthurus pyroferus*. 113 mm. specimen, Marshall Islands (after Schultz and Woods, 1953, retouched).

The types of this species were destroyed in Manila during World War II, and to my knowledge, no other specimens are in existence. Herre (1934: 62) recorded the species (as *Acanthurus leucocheilos*) from a specimen (Stanford Mus. No. 26401) from the Philippines. I examined it and found that it is *Acanthurus pyroferus*.

Fowler and Bean (1929: 225) erroneously placed *Acanthurus leucocheilus* Herre in the synonymy of *Hepatus grammoptilus* (Richardson). The specimens which these authors identified as *grammoptilus* are *A. xanthopterus* and *A. dussumieri*. *A. leucocheilus*, as originally described, is probably a valid species.

Acanthurus pyroferus Kittlitz
Figs. 2*k*, 15

Acanthurus pyroferus Kittlitz (1834: 191, pl. 12, fig. 2) (Ulea Island = Woleai Atoll, Caroline Islands); Günther (1861: 337); Günther (1873: 113).

Acanthurus armiger Cuvier and Valenciennes (1834: 234).

Acanthurus celebicus Bleeker (1852: 761) (Macassar, Celebes); Kner (1865–67: 211) (Madras); Günther (1861: 339); Günther (1873: 115, pl. 73, fig. B) (Solomon Islands and Tahiti); Day (1889: 142) (Malay Archipelago); Herre (1927: 417, pl. 13, fig. 1) (Mindoro, Philippine Islands); de Beaufort (1951: 141) (Java and Adonare).

Acanthurus fuscus Steindachner (1861: 176, pl. 5) (Ambon, East Indies); Günther (1861: 339); de Beaufort (1851: 137).

Rhombotides celebicus Bleeker (1863*b:* 235) (Ternate, East Indies).

Acanthurus Celebicus Day (1876: 206) (Malay Archipelago).

Acanthurus tristis Tickell *in* Day (1888: 788) (Arraken, Burma); Myers (1951: 26).

Hepatus pyriferus Jordan and Seale (1906: 350) (error for *pyroferus*).

Hepatus celebicus Jordan and Seale (1906: 352); Jordan and Seale (1907: 34) (Philippine Islands).

Hepatus pyroferus Fowler (1928: 272).

Hepatus leucosternon. Fowler (1928: 272); Fowler and Bean (in part) (1929: 243, fig. 14) (Riu Kiu Islands, Philippine Islands, and East Indies); Aoyagi (1943: 207, text fig. 52, pl. 5, fig. 13) (Riu Kiu Islands).

Acanthurus leucocheilos. Herre (1934: 62) (Linapacan, Philippine Islands).

Acanthurus leucosternon. Schultz and Woods *in* Schultz *et al*. (1953: 626, pl. 61, fig. B) (Bikini Atoll, Marshall Islands).

Dorsal rays VIII, 27 or 28; anal rays III, 24 to 26; pectoral rays 16; anterior gill rakers 23 to 26; posterior gill rakers 25 to 27 (raker counts from four specimens from the Marshall Islands); a 109 mm. specimen has 14 upper and 16 lower teeth; a 145 mm. specimen has 16 upper and 18 lower teeth; a 159 mm. specimen has 16 upper and 21 lower teeth.

Snout somewhat produced; snout length 4.6 to 4.7 in standard length; caudal fin lunate, caudal concavity 4 to 5 in standard length; longest dorsal ray about 4.5 in standard length.

TABLE 11

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus pyroferus* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS		ANAL SOFT RAYS		
	27	28	24	25	26
Philippine Islands	5		1	4	
Marshall Islands	2	2		2	2

Color from a 35 mm. Kodachrome transparency (given to me by Leonard P. Schultz) of a Marshall Islands specimen (reproduced in black and white herein as Figure 15): purplish black with an orange area, higher than wide, at edge of gill opening just above base of pectoral fin; a diffuse patch of orange anterior to base of pectoral and a trace of orange just behind eye; a broad black band beginning at upper end of gill opening and extending on to margin of gill cover down to isthmus (this band is more apparent in preserved specimens, as is a black band at the base of the dorsal fin, one at the base of the anal fin, blackish lips, and a narrow black margin around caudal spine socket); a white line under chin extending slightly above rictus; median fins black except for a broad posterior band on back edge of caudal fin which is pale yellow; pectoral fin blackish, especially basally on rays, with a large pale yellow spot in lower central part of fin.

Kittlitz (1834) stated that the species is common at Ulea (Caroline Islands), and the young are dirty yellow in color. I have seen no juvenile specimens of this species. It is possible that Kittlitz might have confused the young of *Acanthurus olivaceus*, which are yellow, with *Acanthurus pyroferus*.

Acanthurus pyroferus occurs in the East Indies and Philippines and into the Indian Ocean at least as far as India. It ranges out into the tropical central Pacific; however it is recorded from only a few of the major island groups. De Beaufort (1951: 142) lists the species (as *A. celebicus*) from Hawaii. In this I believe he is in error.

I know of no type specimen of *Acanthurus pyroferus* Kittlitz. Although no one has identified a specimen of *Acanthurus* as *pyroferus* since Kittlitz (1834), and de Beaufort (1951: 138) regarded it as a problematic species, there is little doubt that it is the same as *Acanthurus celebicus* Bleeker. Kittlitz' figure shows the vertically aligned orange area, which is edged in black, just above the pectoral fin and the prominent, uniformly broad, yellow, posterior margin on the caudal fin. The dorsal and anal fins are relatively elevated, and the snout is produced (although this feature seems to be exaggerated). The dorsal and anal fin ray counts (D VII, 29; A III, 25) check closely (as in most species of *Acanthurus*, the first dorsal spine is very short and covered with skin; it could have been overlooked by Kittlitz, or he may have counted the eighth spine as a soft ray). The narrow ring of white under the chin is not present on the figure, nor is it mentioned in the description. Probably it was missed. There are greater omissions than this from some of the figures and descriptions of better known species of acanthurids from the same paper.

Herre (1927: 418) observed two living specimens from the Philippines and reported that the amount and intensity of red color behind the head and about the pectoral base vary considerably according to light conditions and the state of excitement of the fish.

Acanthurus tristis Tickell (Day) was described as having a caudal fin "nearly white externally" and an irregular black band from the upper edge of the orbit across the top of the opercle to the base of the pectoral fin. Although I have not seen a specimen of *Acanthurus pyroferus* with the black band extending to the eye, Herre's plate (1927: pl. 13, fig. 1) shows this pattern, and I consider it as probably within the range of variability of the species.

Acanthurus pyroferus appears to link the group of three species, *Acanthurus leucosternon*, *Acanthurus glaucopareius*, and *Acanthurus achilles* with the last 11 Indo-West-Pacific species as discussed in this paper (species such as *A. olivaceus*, which have a distinctive color mark on the shoulder region, and large species such as *A. xanthopterus*) and the Atlantic species except *A. coeruleus*. *A. pyroferus* is intermediate in dorsal and anal fin ray counts, tooth structure, and tooth counts. It has a produced snout and white line on the chin in common with the former group and the large, round, gizzard-like stomach of the latter.

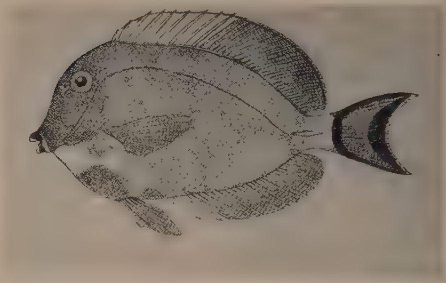


FIG. 16. *Acanthurus leucosternon* (after de Beaufort, 1951).

Acanthurus leucosternon Bennett
Figs. 2*l*, 16

Acanthurus leucosternon Bennett, E. T. (1832: 183) (Ceylon); Bleeker (1853*b*: 48); Bleeker (1856–57: 237) (Batoe Islands, Sumatra); Günther (1861: 340) (Ceylon); Playfair *in* Playfair and Günther (1866: 56) (Zanzibar); Day (1876: 203); de Beaufort (1951: 139, fig. 26) (Pulu Weh and coast of Deli, Sumatra).

Acanthurus Delisiani Cuvier and Valenciennes (1835: 193) (Mauritius).

Acanthurus Delisianus Valenciennes *in* Cuvier (1837: pl. 45); Guérin (1844: pl. 35, fig. 2).

Rhombotides leucosternon Bleeker *in* Bleeker and Pollen (1874: 97).

Acanthurus leucosternum Day (1889: 138).

Dorsal rays IX, 30; anal rays III, 27; pectoral rays 16; 11 upper teeth and 12 lower teeth. All counts based on one 173 mm.

specimen from Mauritius in the Museum of Comparative Zoology at Harvard College. This specimen, the only one which I have examined, was used for the proportional measurements and color description below.

Body depth 1.7 in standard length; caudal concavity 13 in standard length; longest dorsal ray 5.4 in standard length; caudal spine 3 in head length.

Color in alcohol: body bluish gray; head dark brown; chin with a chalky white line at edge of lip which extends a distance equivalent to half the diameter of an eye above the rictus and narrows to a point apically; a broad chalky white band on chest, as wide as depth of caudal peduncle, extending to base of pectoral fin; caudal fin with a white posterior marginal band (equal in width to one-third the diameter of the pupil of the eye), a brownish black submarginal band (an eye diameter in width centrally, but narrowing toward lobes where it meets brownish black upper and lower edges of caudal fin), and a narrow brownish black band across base which connects the dark upper and lower margins of caudal lobes; dorsal fin pale yellow with a narrow white marginal line on upper edge and a black submarginal line; anal fin pale yellow with narrow white outer margin and white line at base; pectoral fin pale yellow; pelvic fins purplish gray with a white margin; region around caudal spine slightly paler than body.

Acanthurus leucosternon resembles *Acanthurus achilles* and *Acanthurus glaucopareius* in morphology and color. It ranges from East Africa to the East Indies, and does not appear to be a common species.

Fowler (1928), Fowler and Bean (1929), Aoyagi (1943), and Schultz and Woods (1953) were all in error in their use of the name *leucosternon* for the species *Acanthurus pyroferus*.

Acanthurus glaucopareius Cuvier

Figs. 1*l*, 2*m*, Pl. 2

Acanthurus glauco-pareius Cuvier (1829: 224) (after Seba) (Günther, 1861, gives the type locality as Tahiti).

Acanthurus ali-ala Lesson (1830: 150) (Oualan).

Acanthurus glaucopareius Kittlitz (1834: 192, pl. 13, fig. 3) (Ulea Island = Woleai Atoll, Caroline Islands); Cuvier and Valenciennes (1835: 190) (Tahiti); Bleeker (1856: 47) (Ambon, East Indies); Günther (1861: 339) (Ambon, East Indies and Tahiti); Günther (1873: 114, pl. 71, fig. A) (Polynesia and East Indies); Schultz (1943: 161) (Phoenix and Samoa Islands); Marshall, N. B. (1950: 194) (Cocos-Keeling Islands); Palmer (1950: 202) (Christmas Island, Indian Ocean); de Beaufort (1951: 138) (Ambon, Misol, and New Guinea).

Rhombotides glaucopareius Bleeker (1865: 288) (Ambon, East Indies).

Teuthis aliala Jordan and Evermann (1898: 1693) (Clarion and Socorro Islands, western Mexico); Jordan and McGregor (1899: 280) (Clarion and Socorro Islands); Seale (1901: 109) (Guam).

Hepatus aliala Snodgrass and Heller (1905: 403) (Cocos Island and Clipperton Island); Jordan and Seale (1906: 350) (Samoa); Aoyagi (1943: 209, pl. 8, fig. 2, pl. 6, fig. 19) (Okinawa).

Acanthurus aliala Herre (1927: 416, pl. 2, fig. 2) (Philippine Islands); Herre (1936: 241) (Cocos Island off Costa Rica, Marquesas Islands, Tuamotu Archipelago, and Society Islands); Schultz and Woods *in* Schultz *et al.* (1953: 627, pl. 65, fig. A) (Marshall Islands).

Hepatus glaucopareius Fowler (1928: 272) (Oceania); Fowler and Bean (1929: 246) (Philippine Islands, Guam, Samoa, and Honolulu).

Hepatus aliala japonicus Schmidt (1930*b:* 102, pl. 6, fig. 3) (Riu Kiu Islands).

Teuthis glaucopareius Whitley and Colefax (1938: 297) (Nauru Island).

Hepatus glauco-pareius Fowler (1938: 103) (Takaroa, Tuamotu Archipelago).

Teuthis japonicus Fowler (1946: 197).

Teuthis glauco-pareius Fowler (1949: 103) (Jarvis Island).

Acanthurus sp. one Harry (1953: 149) (Raroia, Tuamotu Archipelago).

Dorsal rays IX, 28 to 31; anal rays III, 26 to 28; pectoral rays 16; anterior gill rakers 17 to 19; posterior gill rakers 18 to 20 (raker counts from specimens from the Phoenix Islands); 80 mm., 108 mm., and 133 mm. specimens have 10 upper and 10 lower teeth; 153 mm. and 171 mm. specimens have 10 upper and 12 lower teeth.

TABLE 12

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus glaucopareius* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS				ANAL SOFT RAYS		
	28	29	30	31	26	27	28
East Indies			1			1	
Philippine Islands	1				1		
Mariana Islands		1	1		1	1	
Marshall Islands	2	6	6	1	2	12	1
Gilbert Islands	1	7	3	1	5	6	1
Samoa Islands		3	4	1	2	5	1
Phoenix Islands	1	3	6	2	3	9	
Tuamotu Archipelago	2	3	4		2	5	2
Marquesas Islands		1			1		
Line Islands		1				1	
Galapagos Islands		1	1	1		2	1
Cocos Island, Costa Rica	1	3	4		2	4	2
Hawaiian Islands		1	1			2	

Depth of body 1.7 to 1.85 in standard length; caudal concavity 10 to 14.5 in standard length; width of mouth from rictus to rictus 4.5 to 5.3 in head length; length of snout 4 to 4.3 in standard length.

Color (in alcohol) dark purplish brown; a whitish elliptical area below and adjacent to eye; a pale line under chin extending and narrowing about one-half eye diameter in distance above rictus; no pale area around caudal spine and no white mark on opercle; caudal fin abruptly yellowish white with a pale yellow band (the posterior edge of which is bordered with a narrow dark line), about one-fourth to one-third the diameter of the eye in width, in outer part of fin paralleling posterior margin; dorsal and anal fins colored like body except basally where there is a prominent pale yellowish white (yellow in life) band which broadens posteriorly in fin to about three-fourths the length of the last few rays; dorsal and anal fins with a narrow white margin and a black submarginal line; rays of pectoral fin dusky, membranes clear; pelvic fins dark with narrow pale outer margin.

Marshall (1950: 194) and Palmer (1950: 202) recorded a color form of this species which co-exists with the normal one at Cocos-Keeling Islands and Christmas Island, respectively, in the Indian Ocean. The salient feature of this form is the lack of the usual sharp dividing line in color at the caudal flexure. There is a gradual blending of dark body color and pale caudal color over the proximal one-third of the fin. Also the dorsal and anal fins are paler.

Schmidt (1930*b:* 102, pl. 6, fig. 3) described a subspecies, *Acanthurus glaucopareius japonicus*, from the Riu Kiu Islands which Fowler (1946: 197) elevated to species rank. Aoyagi (1943: 210), however, observed this form occurring with the typical *Acanthurus glaucopareius* in the Riu Kius and found intermediates between the two. I examined a 90 mm. specimen of the *japonicus* form at the Academy of Natural Sciences of Philadelphia. It differs from the normal *glaucopareius* chiefly in the presence of a broad pale band running from the eye to the posterior half of the upper lip and a large pale spot at the base of the pectoral fin. There are no obvious meristic differences; the counts of this specimen are: D IX, 28; A III, 26; P 16; 10 upper teeth; 10 lower teeth.

Schultz (1943: 157, 163, fig. 13) described *Acanthurus rackliffei* from the Phoenix Islands. He noted the similarity to *Acanthurus glaucopareius* and *Acanthurus achilles*. In my opinion *A. rackliffei* is a hybrid between these two species (Randall, in press, *d*).

Acanthurus glaucopareius, *Acanthurus achilles*, and *Acanthurus leucosternon* stand apart from other species of the genus principally in having a produced snout, a small mouth with few, relatively large teeth of distinctive structure, a high body, dark purplish color, and a white line on the chin. Also, at least in *A. achilles* and *A. glaucopareius*, the size at transformation from the acronurus to the juvenile stage is very large, about 55 to 60 mm. in standard length. These differences would probably warrant recognition of this group as a subgenus were it not for *Acanthurus pyroferus* which links these three to other species of *Acanthurus*.

The largest specimen of *A. glaucopareius* examined by me measures 171 mm. in standard length. It was collected from Enderbury Atoll in the Phoenix Islands.

Acanthurus glaucopareius appears to be absent from the Indian Ocean except for Christmas and Cocos-Keeling Islands. It occurs in the East Indies and Philippine Islands and is recorded from most of the island groups of the tropical Pacific. It is one of the three species of *Acanthurus* to have crossed the eastern Pacific barrier; it seems to be common in the waters of the Galapagos Islands, Cocos Island, and the Revillagigedo Islands (Mexico). It is usually abundant where it is found; however it is probably the rarest of the species of surgeon fishes in the Hawaiian Islands.

In atolls of the Gilbert Islands, *A. glaucopareius* was most commonly seen on the coralliferous terrace of the outer reef, especially near the entrances to surge channels; however, it was often observed in coral-rich areas of more sheltered waters.

Many authors have used the name *Acanthurus aliala* Lesson (1830) for this species. It is true that the name *glaucopareius* does not appear on page 212 of Bloch and Schneider (1801) even though a description which fits this species can be found on this page in a separate section under the heading *Acanthurus nigricans*. Cuvier's listing (1829: 224) of *Acanthurus glaucopareius* and reference to the work of the prelinnaean author Seba (1758) who figured the species, however, clearly predates Lesson.

Acanthurus achilles Shaw

Figs. 1*k*, 2*n*, Pl. 2

Acanthurus Achilles Shaw (1803: 383) (no locality); Cuvier and Valenciennes (1835: 218).

Acanthurus achilles Günther (1861: 340) (China); Günther (1873: 115, pl. 71, fig. B) (Polynesia); Waite (1897: 188) (Funafuti, Ellice Islands); Steindachner (1901: 493) (Honolulu); Jordan and Jordan (1922: 65) (Hawaiian Islands); Herre (1927: 414, pl. 2, fig. 1) (Guam); Schultz (1943: 162) (Phoenix and Samoa Islands); Schultz and Woods *in* Schultz *et al.* (1953: 629, pl. 65, fig. B) (Marshall Islands); Harry (1953: 147) (Raroia, Tuamotu Archipelago).

Acanthurus aterrimus Günther (1873: 114, pl. 77, fig. B) (Samoa).

? *Acronurus formosus* Castelnau (1873: 104) (Torres Strait); Macleay (1881: 528).

Teuthis achilles Fowler (1899: 494) (Caroline Islands); Jenkins (1903: 475) (Hawaiian Islands).

Hepatus achilles Jordan and Evermann (1905: 384, pl. 58) (Honolulu); Jordan and Seale (1906: 350) (Samoa); Fowler (1928: 273) (Oceania); Fowler and Bean (1929: 247) (Fanning Island, Samoa, and Hawaiian Islands); Fowler (1938: 104, 184) (Takaroa, Tuamotu Archipelago and Tongareva).

Hepatus aterrimus Jordan and Seale (1906: 351); Fowler (1928: 268) (Society Islands); Fowler and Bean (1929: 243).

Teuthis aterrimus Fowler (1949: 103).

Dorsal rays IX, 29 to 33; anal rays III, 26 to 29; pectoral rays 16; anterior gill rakers 16 to 20; posterior gill rakers 18 to 20 (raker counts from specimens from the Phoenix Islands); 84 mm., 140 mm., and 155 mm. specimens have 8 upper and 10 lower teeth; a 185 mm. specimen has 10 upper and 12 lower teeth.

TABLE 13
VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus achilles* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS					ANAL SOFT RAYS			
	29	30	31	32	33	26	27	28	29
Marshall Islands	2	10	12	7		1	7	14	9
Gilbert Islands			4				1	3	
Samoa Islands		6	10	16			4	13	15
Phoenix Islands	1	3	5	2			3	6	2
Line Islands	2	1	2			1	1	2	1
Malden Island	1	1	1				3		
Wake Island		3	3	1			2	4	1
Hawaiian Islands	1	4	8	4	2	1	4	8	6
Johnston Island			8	2				6	4

Depth of body 1.75 to 1.9 in standard length; caudal concavity 5.5 to 8 in standard length; width of mouth from rictus to rictus 4.5 to 6 in head length; length of snout 3.9 to 4 in standard length.

Color (in alcohol) blackish brown with a large oval pale yellow (orange in life) area extending forward from rear of caudal spine; broad median portion of opercular membrane snow white; pale line on chin ending at rictus; basal one-third of caudal fin dark like body; next one-third of fin light orangish brown, bordered posteriorly with a prominent black band which follows the contour of the hind edge of the fin; outer one-fourth to one-third of caudal fin white; dorsal and anal fins colored like body except for a pale line at the base which is only slightly broader posteriorly than anteriorly and a narrow white margin; pectoral rays black, membranes pale; pelvics dark brown with outer margins white.

The large elliptical orange spot on the posterior part of the body of *A. achilles* does not appear until a standard length of about 65 to 70 mm. is attained. Günther (1873) described a juvenile *A. achilles* which had not yet developed its orange spot as a new species, *A. aterrimus*. Schultz (1943: 162) corrected this error.

The acronurus of *A. achilles* (Fig. 1*k*) reaches a large size, about 60 mm. in standard length. It is spotted with black, a characteristic which one usually associates with the acronuri of *Naso*.

Acronurus formosus Castelnau may be the acronurus of *A. achilles*. It was described as having four rows of black spots and the dorsal and anal fin ray counts were high as in *achilles*. Whitley (1940: 425) selected the largest of Castelnau's specimens (62 mm. in standard length) as lectotype and figured it (fig. 42), but did not show any spots. Whitley's counts are also high (D VIII, 31?; A III, 32?). The specimen was collected from the Torres Strait which separates New Guinea from Australia. *Acanthurus achilles* is not recorded from the East Indies, which suggests that the specimen may be the acronurus of *A. leucosternon* which I have not seen.

Acanthurus achilles is common throughout Oceania. It is not known from the Indian Ocean. With the possible exception of the specimen of *Acronurus formosus*, it appears to be absent from the East Indies. The only record of *A. achilles* from the Philippine Islands is the listing of the name with a question mark by Elera (1895: 532). As he did not include *A. glaucopareius* among the surgeon fishes in his catalog, it seems possible that he might have confused these two species. Herre (1927) included *A. achilles* in his work on Philippine surgeon fishes only because he believed the species should occur there. Fowler and Bean (1929) did not find any specimens among the extensive "Albatross" collections of fishes from the Philippines and East Indies; these authors recorded the species from the Philippines on the strength of Elera's dubious record. Herre (1953: 532) erred in listing *achilles* in his checklist of fishes of the Philippines on the basis of his 1927 work. *A. achilles* is not known from the Riu Kiu Islands or Japan. Günther (1861: 340), however, listed it from China; this record is inconsistent with the known distribution and should be checked.

Acanthurus achilles is most often found in inshore regions of moderately rough water.

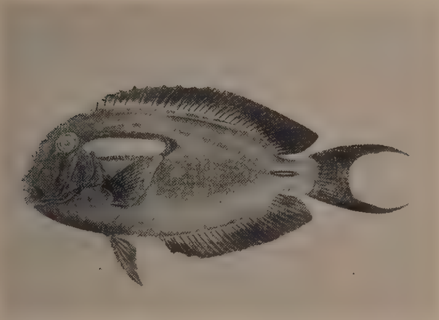


FIG. 17. *Acanthurus olivaceus* (after Schultz and Woods, 1953, retouched).

At atolls in the Gilbert Islands the species was frequently observed in surge channels of the windward reef.

The largest specimen seen by me is 195 mm. in standard length; it was collected at Malden Island.

For further remarks on *A. achilles* see discussion under *A. glaucopareius*.

Acanthurus olivaceus Bloch and Schneider

Figs. 1*f*, 2*o*, 17

Acanthurus Nigricans var. *Olivaceus* Bloch and Schneider (1801: xxxviii, 213–214) (Tahiti).

Acanthurus eparei Lesson (1830: 147, pl. 27, fig. 1) (Tahiti).

Acanthurus olivaceus Kittlitz (1834: 189, pl. 12, fig. 1) (Caroline Islands); Günther (1861: 336) (Tahiti and Fiji Islands); Günther (1873: 113) (East Indies and South Seas); Steindachner (1901: 493) (Honolulu); Jordan and Jordan (1922: 65) (Hawaiian Islands); Herre (1927: 413, pl. 12, fig. 1) (Philippine Islands); Schultz (1943: 166) (Samoa Islands); de Beaufort (1951: 154) (East Indies); Schultz and Woods *in* Schultz *et al.* (1953: 632, pl. 67) (Marshall Islands).

Acanthurus humeralis Cuvier and Valenciennes (1835: 231) (Caroline Islands and Tahiti); Eydoux and Souleyet (1841: 169, pl. 2, fig. 3) (Hawaiian Islands); Bleeker (1852: 762) (Macassar, Celebes).

Ctenodon erythromelas Swainson (1839: 256) (error or emendation for *Acanthurus eparei* Lesson).

Harpurus paroticus Forster (1844: 183).

Acanthurus chrysosoma Bleeker (1857: 67) (Kajeli); Günther (1861: 332); de Beaufort (1951: 165) (East Indies).

? *Rhombotides xanthosoma* Bleeker (1865: 288) (error for *chrysosoma*?).

Rhombotides olivaceus Bleeker (1865: 288) (Ambon, East Indies).

Teuthis olivaceus Seale (1901: 107) (Guam); Jordan and Evermann (1902: 358, fig. 23) (Formosa); Jenkins (1903: 476) (Hawaiian Islands).

Hepatus olivaceus Jordan and Evermann (1905: 385, fig. 166); Jordan and Seale (1906: 350) (Samoa); Jordan and Richardson (1908: 270) (Cagayancillo, Philippine Islands); McCulloch (1922: 243) (Capricorn Islands, Queensland); Fowler (1928: 271) (Oceania); Fowler and Bean (1929: 231) (Philippine Islands, Okinawa, Samoa, and Hawaiian Islands); Schmidt (1930*a:* 556) (Riu Kiu Islands); Fowler (1931: 345) (Honolulu); Fowler (1938: 232) (Honolulu); Aoyagi (1943: 211, pl. 5, fig. 15, teeth only) (Riu Kiu Islands); Hiyama (1943: 94, pl. 20, fig. 55).

Hepatus chrysosoma Fowler (1928: 269); Fowler and Bean (1929: 214).

Dorsal rays IX, 23 to 25; anal rays III, 22 to 24; pectoral rays 16 or 17 (usually 17); anterior gill rakers 24 to 28; posterior gill rakers 23 to 27 (raker counts from Hawaiian specimens); a 44 mm. specimen has 14 upper and 14 lower teeth; a 123 mm. specimen has 14 upper and 16 lower teeth; a 138 mm. specimen has 16 upper and 18 lower teeth; a 208 mm. specimen has 18 upper and 20 lower teeth; a 225 mm. specimen has 20 upper and 21 lower teeth.

Caudal fin of adults strongly lunate, caudal concavity (in specimens greater than 180 mm. in standard length) contained 4 to 5 times in standard length; in specimens about 100 mm.

TABLE 14

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus olivaceus* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS			ANAL SOFT RAYS		
	23	24	25	22	23	24
Philippine Islands		3		1	2	
Okinawa	1	2		1	2	
Mariana Islands		2		1		1
Caroline Islands	1			1		
Marshall Islands	2	12	4	3	9	6
Gilbert Islands		1	1	1		1
Samoa Islands	2	3		2	3	
Society Islands	1	1			2	
Hawaiian Islands	2	13	3	5	10	3
Johnston Island			1		1	

in standard length, the caudal concavity is contained about 9 times in the standard length; snout length 4.5 to 4.9 in standard length; longest soft dorsal ray 5.5 to 6 in standard length; eye of 104 mm. specimen 3.3 in head length; eye of 208 mm. specimen 4.5 in head length; caudal spine of 104 mm. specimen 3.5 in head length; caudal spine of 208 mm. specimen 2.5 in head length.

Large adult males (about 170 mm. or greater in standard length) develop a definite convexity in the profile of the snout which may permit determination of the sex of specimens without resorting to examination of the gonads. This sexual dimorphism of large adults is evident to a greater or less degree in the remaining Indo-West-Pacific species considered in this work and possibly also the Atlantic species except *A. coeruleus*. In most of the species the profile of the head of the female also becomes more convex with age. Males the same size, however, show distinctly greater convexity than females. All of these species have a large, round, very thick-walled stomach.

Color in life from a 35 mm. Kodachrome transparency taken by the author of a 132 mm. specimen speared at Arno Atoll, Marshall Islands: dark grayish brown with a bright orange horizontal band, broadly bordered with purplish black, extending posteriorly from upper end of gill opening a distance greater than the length of the head; a dull orange line at base of dorsal fin; a similar, but fainter, line at base of anal fin; a large crescentic white area in centro-posterior part of caudal fin; rest of caudal fin, especially the lobes, spotted with dark brown; other fins colored like body except outer portion of pectoral which is pale; a faint longitudinal banding may be seen in soft portion of dorsal fin. Many adult specimens have been observed on which the color of the body posterior to a vertical at about the level of the fifth dorsal soft ray is much darker than that in front of this demarcation.

D. W. Strasburg (MS) has pointed out that the young of *Acanthurus olivaceus* are yellow. From a transformation size of about 29 mm. in standard length to a length of about 55 mm. the body color is bright yellow. The margins (except posterior) of the median fins and lateral outer edge of the pelvic fins are narrowly black. At a size of about 45 mm. in standard length the mark on the shoulder region first makes its appearance as a small dusky area. Specimens larger than about 55 mm. in standard length show a progressive accumulation of brown pigment until, at a standard length of about 85 mm., the brown color predominates. The shoulder bar first acquires a pale orange center at a standard length of about 55 mm.

Acanthurus chrysosoma Bleeker is probably the young of *Acanthurus olivaceus*. Bleeker's type specimens were 43 to 51 mm. in length. The color when fresh was orange-yellow with brownish edges on the dorsal, anal, and caudal fins.

A. olivaceus occurs from the East Indies to Oceania. Records from the Indian Ocean, such as from Mauritius, all appear to be the closely related *A. tennenti*.

A. olivaceus is usually found in fairly deep water, about 30 feet or more in depth. It is most commonly seen where much of the bottom is sandy.

Acanthurus tennenti Günther

Figs. 2*p*, 18

Acanthurus tennenti Günther (1861: 337) (Ceylon); Day (1889: 140).

Acanthurus Tennentii Day (1876: 204).

Acanthurus plagiatus Peters (1876: 439) (Mauritius).

Acanthurus olivaceus. Sauvage (1891: 343) (Mauritius).

Hepatus sohal. Fowler and Bean (1929: 216) (locality unknown).

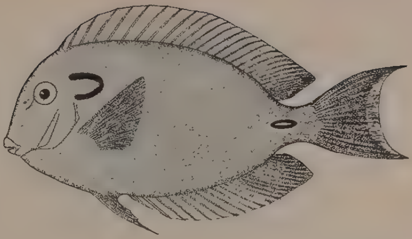


FIG. 18. *Acanthurus tennenti.* 116 mm. specimen, locality unknown. Drawing by author.

Dorsal rays IX, 23 or 24; anal rays III, 22 or 23; pectoral rays 16 (fin ray counts from 7 specimens from Mauritius and Ceylon); anterior gill rakers 25, posterior gill rakers 25 (based on one specimen); a 105 mm. specimen has 15 upper and 16 lower teeth; a 214 mm. specimen has 20 upper and 22 lower teeth.

Caudal fin lunate, caudal concavity varying from 10 in standard length of a 105 mm. specimen to 5 in standard length of a 214 mm. specimen.

Color (in alcohol) brown with a horseshoe-shaped black mark (open end pointing anteriorly) just behind upper edge of gill opening, at level of eye (in specimens of about 120 mm. or more in standard length this mark is broken posteriorly, forming two longitudinal curved bands; in very large specimens these bands are straighter, more elongate, and attenuate posteriorly); caudal spine enclosed in a prominent black area which, in turn, is surrounded by a bluish white region. This dark area becomes progressively larger with age and its bluish white margin relatively narrower (in a 214 mm. specimen the black area was oval in shape, slightly more pointed anteriorly, 37 mm. in length and 16 mm. high; the bluish white margin was a little greater than 1 mm. in width); caudal fin with a broad crescentic white area posteriorly; large specimens with pale margins on the very elongate upper and lower caudal lobes; dorsal and anal fins brown with no trace of banding; pectoral fin brown with a broad pale posterior margin (more distinct in large specimens); pelvic fins brown.

Fowler and Bean (1929: 216) misidentified a 116 mm. specimen of this species (U.S.N.M. No. 21294) as *Hepatus sohal*. It is this specimen which I have drawn as Figure 18. No field data or locality are available.

A. C. Wheeler kindly sent an X-ray, a drawing, and other data on the type specimen in the British Museum. The specimen is 103 mm. in standard length and is conspecific with the Fowler and Bean specimen.

Peters (1876: 439) described *Acanthurus plagiatus* as having two elongate triangular black marks on the shoulder, a black area with blue margin around the caudal spine, and a lunate caudal fin with a broad yellow posterior margin and a narrow yellow edge on the upper and lower caudal lobes. Had I not seen the five specimens in the Museum of Comparative Zoology at Harvard College which connect the large *plagiatus* form to *A. tennenti* of a little over 100 mm. in standard length, I would have probably considered Peters' species as valid.

Acanthurus tennenti is very closely related to *Acanthurus olivaceus*, and, with the possible exception of pectoral fin ray counts (more specimens needed), I can separate the two only by color. To my knowledge they are not known from the same area, *A. tennenti* occurring in the Indian Ocean and *A. olivaceus* in the East Indies and Oceania. Sauvage (1891: 343) (after Liénard) recorded *A. olivaceus* from Mauritius; however, he described it as having two oblong black marks on the suprascapular region, thus indicating that he had a large specimen of *A. tennenti*. It is possible that the distinction between *A. olivaceus* and *A. tennenti* is subspecific; however, the color differences as noted in the key are greater than those seen on other similar pairs of acanthurids (such as *Acanthurus xanthopterus* and *Acanthurus mata*) which may be observed together.

Acanthurus fowleri de Beaufort

Fig. 2*q*, Pl. 3

Acanthurus bariene. Herre (in part) (*non* Lesson) (1927: 409) (Bantayan Island, Philippine Islands).

Hepatus pyroferus. Fowler and Bean (*non* Kittlitz) (1929: 232) (Philippine Islands and East Indies).

Acanthurus fowleri de Beaufort (1951: 149) (after Fowler and Bean).

Dorsal rays IX, 27; anal rays III, 25 or 26; pectoral rays 15 or 16; anterior gill rakers 23 to 25; posterior gill rakers 29 to 32. All counts based on five specimens from the Philippine Islands. A 165 mm. specimen has 17 upper and 18 lower teeth; a 270 mm. specimen has 18 upper and 20 lower teeth.

A 165 mm. specimen has a body depth which is contained 1.9 times in standard length, a snout length which is 4.4 in standard length, a caudal concavity which is 4.9 in standard length, an eye diameter which is 4.7 in head length, and a caudal spine length which is 3.7 in head length. A 270 mm. specimen has a body depth which is contained 2.3 times in standard length, a snout length which is 4.65 in standard length; a caudal concavity which is 4.4 in standard length, an eye diameter which is 5.7 in head length, and a caudal spine length which is 2.3 in head length.

Color (in alcohol) brown with numerous fine longitudinal pale lines on body which are about equal in width to the dark interspaces; a black triangular or horseshoe-shaped mark on shoulder region, the upper end of which is just above upper end of gill opening and the lower end approaches the upper part of the axil of the pectoral fin (the width of the band forming this mark is about one-half the diameter of the pupil of the eye); sheath of caudal spine and a broad margin around socket of spine black; base of caudal fin abruptly pale; upper and lower lobes of caudal slightly lighter than dark brown center of fin; pectoral fins brown with a large pale yellow spot in outer upper part; dorsal, anal, and pelvic fins brown.

Fowler and Bean (1929) were in error in calling this species *Hepatus pyroferus* (Kittlitz). De Beaufort (1951) realized this and proposed the name *Acanthurus fowleri*. Fowler and Bean give two detailed color descriptions for the species (1929: 233).

Herre (1927: 411) included in *Acanthurus bariene* a 240 mm. specimen from Bantayan Island which had a violet-black line encircling an area on the shoulder more than twice the size of the eye, the caudal fin with a bluish white ring at the base and the central part black, and the caudal spine in a black spot. Probably he was describing a specimen of *A. fowleri*.

Acanthurus fowleri is unknown outside the Philippine-East Indian region.

Acanthurus bariene Lesson

Fig. 2*r*, Pl. 3

acanthurus bariene Lesson (1830: 150) (Waigiou Island = Waigeo Island, New Guinea).

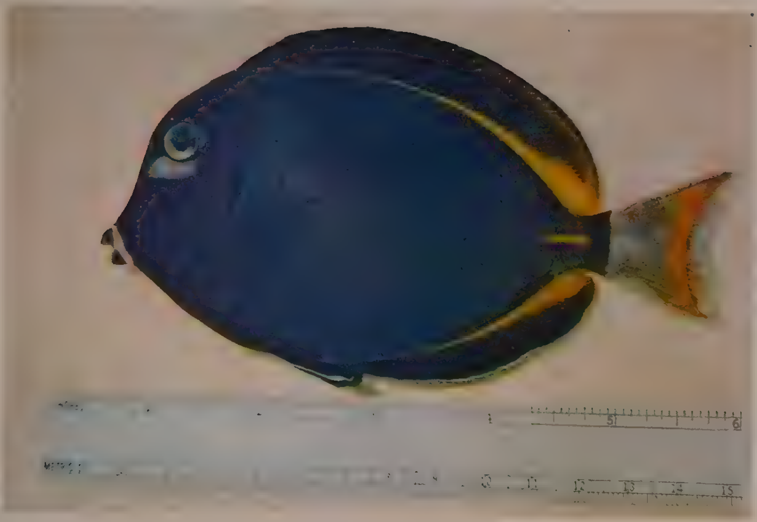
Acanthurus nummifer Cuvier and Valenciennes (1835: 234); Günther (1861: 338).

Acanthurus kingii Bennett, E. T. (1835: 119) (Port Praya).

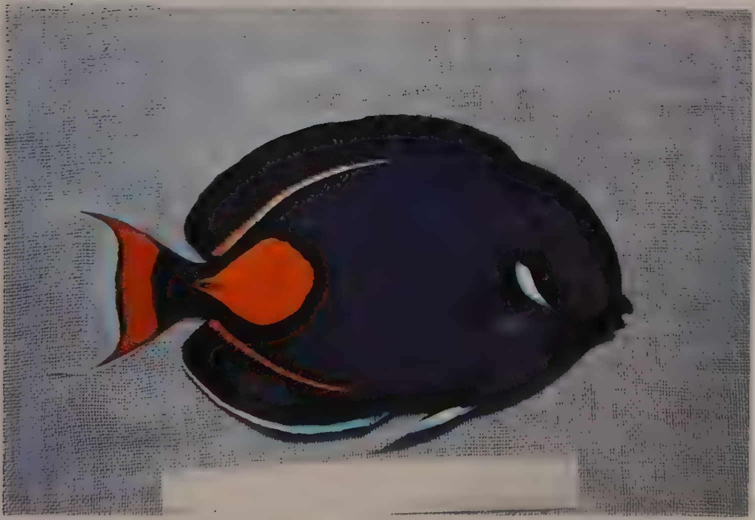
Rhombotides nummifer Bleeker (1868: 297).

Hepatus bariene Jordan and Seale (1906: 352); Fowler and Bean (in part) (1929: 222) (Philippine Islands); Aoyagi (1943: 212, pl. 5, fig. 11, teeth only) (Okinawa).

Acanthurus bariene Herre (in part) (1927: 409,



Acanthurus glaucopareius, Gilbert Islands.



Acanthurus achilles, Hawaiian Islands.

pl. 1, fig. 2) (Philippine Islands); Smith (in part) (1949: 240) (Mozambique); de Beaufort (1951: 153).

Dorsal rays IX, 26 to 28; anal rays III, 25 or 26; pectoral rays 17 (fin ray counts based on six specimens from the Philippines); anterior gill rakers 19 to 23; posterior gill rakers 22 to 24 (raker counts from Philippine specimens); a 167 mm. specimen has 18 upper and 20 lower teeth; a 290 mm. specimen has 21 upper and 22 lower teeth.

Depth of body 1.9 to 2 in standard length; caudal concavity varying from 6.7 in standard length of 167 mm. specimen to 3.7 in standard length of 290 mm. specimen; longest dorsal ray varying from 4.9 in standard length of 167 mm. specimen to 5.3 in standard length of 290 mm. specimen.

Color (in alcohol) brown with numerous fine bluish gray longitudinal lines faintly visible on side of body; a round black spot, with a diameter about two-thirds that of eye, just above upper end of gill opening at level of eye (in some specimens this spot has a narrow pale blue margin); a dark brown area, about twice as high as maximum width of caudal spine, surrounding caudal spine; base of caudal fin abruptly pale, this pale region shading out a short distance on caudal lobes; central and posterior part of caudal fin brown; dorsal fin brownish yellow with narrow blue marginal and black submarginal lines, traces of dark longitudinal lines in outer part of fin, and a dark brown line at the base with a bluish gray line adjacent and distal to it; paired fins brown; opercular membrane dark brown.

H. W. Fowler and others have erred in applying the name *bariene* to the species *Acanthurus dussumieri* Cuvier and Valenciennes.

Acanthurus bariene appears to range from East Africa to the Riu Kiu Islands.

Acanthurus gahhm (Forskål)

Fig. 2*s*, Pl. 3

Chaetodon nigro-fuscus var. *Gahhm* Forskål (1775: xiii, 64) (Red Sea).

Chaetodon Gahm Linnaeus and Gmelin (1788: 1268).

Acanthurus gahm Cuvier and Valenciennes (1835: 219) (Red Sea and Mauritius); Günther (1861: 338); Klunzinger (1871: 506) (Red Sea); Günther (1873: 113, pl. 74) (Red Sea to the South Seas); Weber (1913: 318) (Saleyer, East Indies); Herre (1927: 411, pl. 12, fig. 2) (Philippine Islands); Herre (1936: 241) (Bora Bora and New Hebrides).

Acanthurus gahhm Bleeker (1858: 8) (Macassar, Celebes); de Beaufort (1951: 150) (East Indies).

? *Acanthurus gahmoides* Guichenot (1862: C. 8) (Réunion).

Rhombotides gahhm Bleeker (1865: 288) (Ambon, East Indies).

Acanthurus (*Rhombotides*) *gahm* Klunzinger (in part) (1884: 84) (Red Sea).

Hepatus nigricans. Jordan and Seale (1906: 351) (Samoa); Fowler (1923: 386) (Honolulu?); Fowler (1928: 272) (Oceania); Fowler and Bean (in part) (1929: 233) (Philippine Islands, East Indies, and Fiji).

Acanthurus gahm nigricauda Duncker and Mohr (1929: 75) (South Seas).

Acanthurus nigricans. Schultz (1943: 166) (Phoenix and Samoa Islands); Smith (1949: 240, pl. 36, no. 612) (east coast of Africa south to Durban); Schultz and Woods *in* Schultz *et al*. (1953: 633, pl. 68) (Marshall and Mariana Islands); Harry (1953: 148) (Raroia, Tuamotu Archipelago).

Hepatus nigrofuscus, Hiyama (1943: 94, pl. 20, fig. 56).

Dorsal rays IX, 25 to 28; anal rays III, 23 to 26; pectoral rays 17; anterior gill rakers 20 or 21; posterior gill rakers 20 to 26 (raker counts from Philippine specimens); a 25 mm. specimen has 14 upper and 14 lower teeth; a 46 mm. specimen has 15 upper and 16 lower teeth; a 74 mm. specimen has 16 upper and 16 lower teeth; a 135 mm. specimen has 16 upper and 18 lower teeth; a 170 mm. specimen has 17 upper and 19 lower teeth; a 195 mm. specimen has 18 upper and 20 lower teeth; a 226 mm. specimen has 19 upper and 22 lower teeth. The number of denticulations on the teeth decrease with age (see Table 16).

TABLE 15
VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus gahhm* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS				ANAL SOFT RAYS			
	25	26	27	28	23	24	25	26
Mauritius........		1		1		1	1	
New Guinea.....				1			1	
Philippine Islands.	1	4	3		1	4	3	
Okinawa.........		1				1		
Palau Islands.....		3	4	1		1	4	3
Solomon Islands..	1						1	
Fiji Islands.......	1				1			
Mariana Islands...	1	1	2			1	2	1
Wake Island.....	2	2	1			3	1	1
Marshall Islands..		3	4			4	3	
Gilbert Islands...	1	7	4			4	7	1
Samoa Islands....		1	2	1			4	
Phoenix Islands...		1				1		
Society Islands...			1				1	

Caudal fin progressively more lunate with age, caudal concavity 6.5 in standard length of 76 mm. specimen and 3.6 in standard length of 237 mm. specimen; depth of body varying from 1.9 in standard length of 76 mm. specimen to 2.2 in 237 mm. specimen; snout length 4.3 to 4.5 in standard length; caudal spine 7.5 in head length of 76 mm. specimen, 4.5 in head length of 237 mm. specimen.

Color (in alcohol) brown, without lines on the body or spots on the head; a horizontal black band (usually rounded posteriorly) running backward from upper edge of gill opening (this band first appears in specimens about 55 to 60 mm. in standard length; on a 96 mm. specimen the length of the band is contained 7.6 times in the standard length; on a 237 mm. one the band is 5.5 in the standard length); a long lanceolate black line extending anteriorly from caudal spine (this line does not appear until a standard length of about 100 mm. is attained; it becomes relatively longer in larger specimens and may reach half way from the caudal spine to the base of the pectoral fin on large specimens); caudal fin brown with prominent pale posterior margin (caudal fin of young entirely pale) which is broader in middle portion of fin, but narrows and disappears on caudal lobes (greatest width of posterior caudal margin of 96 mm. specimen contained 3.5 times in diameter of eye; greatest width of margin in 237 mm. specimen 4 in eye); base of caudal fin usually abruptly pale; outer one-third of pectoral fin pale (the inner half of this pale portion yellow in life); remaining fins brown.

Hiyama (1943: pl. 20, fig. 26) has figured the species [erroneously labelled *Hepatus nigrofuscus* (Forskål)] in the usual brown color form. Herre (1927: pl. 12, fig. 2) and Smith (1949: pl. 36, no. 612) have portrayed a bluish form with yellow dorsal and anal fins. Herre noted and figured an elongate dark blue spot on the nape anterior to the origin of the dorsal fin. He observed a living specimen in an aquarium which varied in color at different times from grayish blue to brownish gray. A specimen in the blue color phase with yellow fins was collected at Wake Island by W. A. Gosline and myself. It was not as light a blue as figured by Herre and by Smith but was

TABLE 16
THE CHANGE IN THE NUMBER OF DENTICULATIONS ON THE TEETH OF SPECIMENS OF *Acanthurus gahhm* OF INCREASING STANDARD LENGTH

STANDARD LENGTH (*mm.*)	NUMBER ON UPPER TEETH	NUMBER ON LOWER TEETH
25	17	17
35	15–16	11
42	15–16	11–12
48	14–15	10–11
57	14	10
75	12–13	9
115	10–11	8
135	9–10	8
168	9	7–8
191	7–8	7–8

dark purplish gray in color. An elongate purple mark was clearly visible just in front of the origin of the dorsal fin.

Forskål (1775: 64) listed *gahhm* as a variety of *Chaetodon nigrofuscus*. His description is incomplete, but it applies to the species as here interpreted better than any other known Red Sea species of the genus. The color of the fish was given as black with the base of the caudal fin violet and the hind margin of the pectoral fin yellow.

Many recent authors have used the specific name *nigricans* for *Acanthurus gahhm*. *Chaetodon nigricans* Linnaeus, however, appears to be a species of *Naso*. The species described by Hasselquist (1757: 332), to which Linnaeus refers in his listing of *Chaetodon nigricans*, is definitely a *Naso*.

Acanthurus gahhm ranges from East Africa to Oceania. It is known from most of the island groups in Oceania. There is only one record from the Hawaiian Islands, that of Fowler (1923: 386) who used the name *Hepatus nigricans* for the species. He included no descriptive information with the record, and I have been unable to locate his specimen(s). One adult specimen of *Acanthurus olivaceus* from Johnston Island in the Bishop Museum was identified as *Hepatus nigricans* by Fowler. It is possible that the single Hawaiian record is a misidentification.

At Onotoa Atoll in the Gilbert Islands, adult *Acanthurus gahhm* were commonly seen around isolated coral heads in sandy regions of the lagoon, and the young were abundant in lagoon tide pools. No juvenile or adult individuals were observed in outer reef areas.

Acanthurus maculiceps (Ahl)

Fig. 2*t*, Pl. 3

Hepatus maculiceps Ahl (1923: 36) (Talassia, New Britain); Fowler (1928: 269); Fowler and Bean (1929: 240, fig. 13) (Philippine Islands and East Indies); Aoyagi (1943: 212, text fig. 53, pl. 4, fig. 10) (Okinawa).
Hepatus nigricans. Fowler and Bean (in part) (1929: 233) (Celebes).
Acanthurus maculiceps de Beaufort (1951: 152).

Dorsal rays IX, 24 to 26, anal rays III, 23 or 24; pectoral rays 16; anterior gill rakers 19 to 23; posterior gill rakers 21 to 24 (raker counts from Philippine specimens); a 182 mm. specimen has 17 upper and 20 lower teeth; a 222 mm. specimen has 18 upper and 20 lower teeth.

TABLE 17
VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus maculiceps* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS			ANAL SOFT RAYS		
	24	25	26	22	23	24
East Indies		2	1		2	1
Philippine Islands	1	6	3	2	5	3
Gilbert Islands	1	1			2	

Body depth 2 to 2.1 in standard length; caudal concavity varying from 5.7 in standard length of 182 mm. specimen to 3.5 in standard length of 228 mm. specimen; longest dorsal ray 5.4 to 5.5 in standard length; caudal spine 3.1 to 3.2 in head length.

Color (in alcohol) brown with numerous longitudinal paler brown lines on body (difficult to see on some specimens); a black bar, slightly greater than eye diameter in length, extending backward from upper edge of gill opening and often ending in a slight point; a second dark mark, less intense than the first and about the size of the pupil of the eye, just behind eye and often connected narrowly with the black bar; head with numerous pale spots (in average diameter slightly less than half the diameter of the pupil); all fins brown except for a vertical light gray band at base of caudal fin and pale yellow on outer third of upper six branched pectoral rays; nine dark brown longitudinal bands usually visible in dorsal fin; a very dark brown line, which is wider posteriorly, at base of dorsal fin; region around caudal spine dark brown.

The specimen shown in color in Plate 2 was collected from Binang Unang Island, Celebes, by the "Albatross" Expedition. It was misidentified as *Hepatus nigricans* by Fowler and Bean (1929: 236).

Acanthurus maculiceps is known at the present time only from the East Indies, Philippines, Riu Kiu Islands, and the Gilbert Islands.

A 193 mm. specimen collected by the author at Onotoa Atoll in the Gilbert Islands was speared at a depth of about 20 feet on the coralliferous terrace of the outer reef.

Acanthurus auranticavus Randall
Figs. 2*u*, 19

Hepatus nigrofuscus. Fowler and Bean (in part) (*non* Forskål) (1929: 237) (Philippine Islands and East Indies).

Holotype.—United States National Museum Number 136194, Atulayan Island, Lagonoy Gulf, east coast of Luzon, June 17, 1909, "Albatross" Expedition, 203 mm. in standard length.

Paratypes.—U.S.N.M. No. 163823, Mansalay, southeast Mindoro, June 4, 1908, "Albatross" Expedition, 144 mm. in standard length; U.S.N.M. No. 136202, Danawan Island, Borneo, September 27, 1909, "Albatross" Expedition, 208 mm. in standard length; U.S.N.M. No. 136188, Buang Bay, Talajit Island (between Samar and Masbate, Philippine Islands), March 15, 1909, standard length 217 mm. (to be sent to the British Museum); Stanford Mus. No. 47695, Atulayan Island, Lagonoy Gulf, Luzon, June 17, 1909, "Albatross" Expedition, two specimens, 179 and 207 mm. in standard length.

Description (data in parentheses are the extremes in counts and measurements for all the paratypes).—Dorsal rays IX, 26 (25 or 26); anal rays III, 24 (23 or 24, usually 24); pectoral rays 16 (16 or 17); anterior gill rakers 21 (20 to 23); posterior gill rakers 25 (24 to 28); scales from gill opening to posterior end of caudal spine 217 (195 to 233); number of upper teeth 18 (18 or 19); number of lower teeth 18 (18 to 20).

The following measurements are propor-

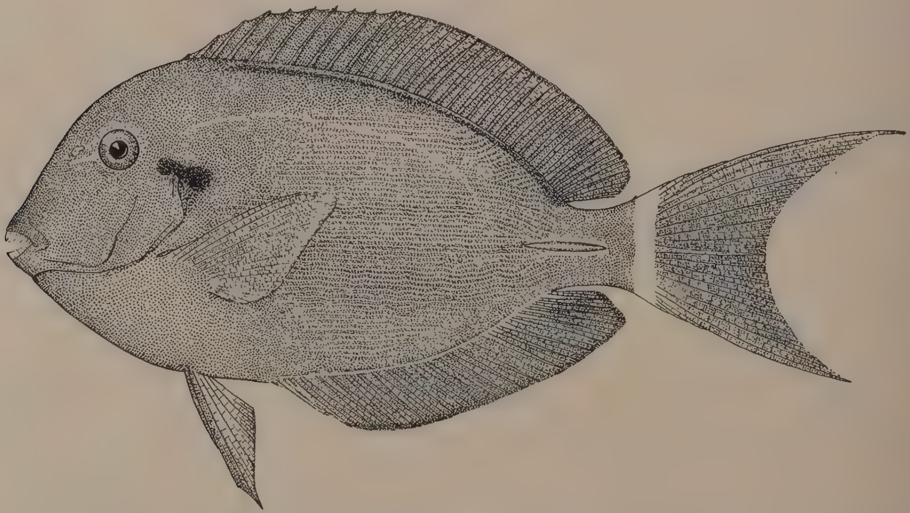


FIG. 19. *Acanthurus auranticavus*, n. sp. Drawing of holotype by Aime M. Awl, United States National Museum.

tions of the standard length: depth of body 2.09 (2.03 to 2.14); length of head 3.98 (3.57 to 3.89); length of snout 4.84 (4.58 to 4.94); length of pectoral fin 3.69 (3.35 to 3.78); length of pelvic fin 4.06 (4.12 to 4.60); pelvic spine 7.65 (6.55 to 8.62); ninth dorsal spine 6.67 (5.34 to 7.24); longest dorsal ray 5.80 (5.24 to 6.50); third anal spine 8.84 (7.39 to 9.44); longest anal ray 6.34 (5.24 to 6.26); caudal concavity 4.41 (4.21 to 6.75).

The following measurements are proportions of the head length: greatest diameter of eye 3.92 (3.51 to 4.53), width of interorbital space 2.76 (2.82 to 3.22), least depth of caudal peduncle 2.25 (2.33 to 2.76), length of caudal peduncle spine 2.22 (2.47 to 4.46), distance from base of upper lip to distal ends of upper teeth 5.67 (6.14 to 6.99).

Color in life of specimens including the holotype (identified by "Albatross" field number) from Fowler and Bean (1929: 238). "Dark brown, sometimes with slate; on fading side shows narrow brown lines with blue-white interspaces as in *Ctenochaetus strigosus*. Breast from pectoral base downward washed orange brown. Caudal spine with bright orange socket. Orange blotch before and behind pupil. Dull obscure orange stripe from eye through nostrils across frontal region. No shoulder blotch. Dorsal slate-gray or almost black basally, and in alcohol few narrow bars appear on hind terminal portion. Anal like dorsal, without dark base and edge narrowly bright blue. Caudal slate, without white tip but white band across base. Pectoral slate, tips somewhat olive yellow. Ventral slate, with slight yellowish dash at tips of last rays."

Color in life of paratype from Buang Bay, Talajit Island from Fowler and Bean (1929: 240): "Body very finely striped with purplish blue and olive. Front and side of head brown becoming blackish on vertical flap. Very short dark blotch behind upper angle of gill opening. Breast mostly dusky, also with orange shades. Fins dull violaceous, dorsal edge somewhat purplish with submarginal translucent bar; anal margin bright purple. White band across caudal base. Caudal spine with orange socket. Paired fins olive or black, without marks or color variation."

Color (in alcohol) brown with about 55 slightly wavy bluish gray longitudinal lines on body (faded in some specimens) which tend to converge posteriorly on caudal spine; a dark brown bar (1.3 eye diameters in length, in the holotype) on shoulder region which is restricted in width as it passes upper end of gill opening; shoulder bar tilted downward so that a line bissecting it passes from the center of the eye to the base of the 18th anal ray; caudal fin yellowish brown with a chalky white bar at base; dorsal fin yellowish brown with a dark brown band at base (broader posteriorly) and an indistinct narrow dark outer margin; anal fin grayish brown with a faint bluish white band at base and an indistinct narrow dark outer margin; pectoral fins yellowish brown; pelvic fins grayish brown; socket of caudal spine and a margin around the socket as wide as half the width of the spine orange-brown.

The shoulder blotch in this species is not black as in *Acanthurus gahhm* and *Acanthurus maculiceps* but dark brown or orange-brown. On some specimens it can be perceived only with difficulty.

Acanthurus auranticavus appears to be most closely related to *Acanthurus maculiceps* from which it differs primarily in shape and color of the shoulder blotch and lack of pale spots on the head; there is no large pale area on the pectoral fin, nor are there prominent bands in the dorsal and anal fins. Also the posterior gill rakers are more numerous in *A. auranticavus*.

The species is named *auranticavus* in reference to the orange socket of the caudal spine.

I have seen specimens only from the Philippine Islands and the East Indies.

Acanthurus grammoptilus Richardson

Figs. 2*v*, 20

Acanthurus grammoptilus Richardson (1843:

176) (Port Essington, N. Australia); Bleeker (1855: 11) (van Diemensland, N. Australia); Günther (1861: 335); Macleay (1878: 354) (Port Darwin, N. Australia); Macleay (1881: 528).

Hepatus nigrofuscus. Fowler and Bean (in part) (1929: 237) (Mansalay, Mindoro, Philippine Islands).

Dorsal rays VIII or IX (one specimen with VIII, four with IX), 25 or 26; anal rays III, 23 or 24; pectoral rays 16 or 17; anterior gill rakers 16 to 18; posterior gill rakers 21 to 23; a 93 mm. specimen has 14 upper and 18 lower teeth; a 205 mm. specimen has 18 upper and 20 lower teeth; a 245 mm. specimen has 18 upper and 20 lower teeth. All counts based on five specimens from Arnhem Land, northern Australia.

Body depth varying from 1.9 in standard length of a 93 mm. specimen to 2.5 in a 245 mm. specimen; caudal concavity 6.3 to 7.7 in standard length; head length 3.4 to 3.7 in standard length; pectoral fin 3.3 to 3.4 in standard length; pelvic fin 3.6 to 4.3 in standard length; length of snout 4.4 to 4.5 in standard length; length of longest dorsal ray 5 to 5.5 in standard length; interorbital space 3.1 to 3.2 in head length; diameter of eye 3.5 in head length of 93 mm. specimen, 5.2 in head length of 245 mm. specimen.

Color (in alcohol) of 245 mm. Arnhem Land specimen brown with narrow light brown longitudinal undulating lines faintly visible on the sides; caudal spines surrounded by a very dark brown area which extends anterior to the spine a distance greater than one eye diameter; base of caudal fin white; rest of fin brown except posterior margin which is narrowly pale; pectoral fin with outer one-third pale, basal two-thirds brown; a light brown area behind eye, outlined by a narrow dark line; five acuminate light brown bands projecting forward from eye and separated by dark brown lines; remainder of head brown with pale brown spots; dorsal and anal fins brown with a narrow dark brown border and traces of narrow dark brown bands in distal part of soft portion of these fins; five narrow dark brown longitudinal bands barely visible in spinous part of dorsal fin; a dark brown band at base of dorsal fin; pelvic fins brown; opercular membrane dark brown. At the upper end of the gill opening there is a faint dark brown elongate blotch which extends posteriorly a distance almost equivalent to an eye diameter.

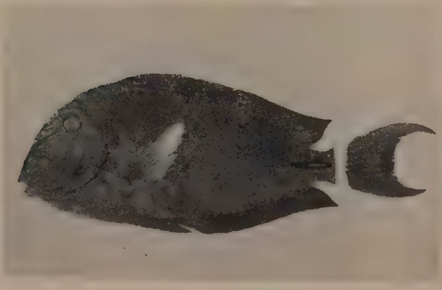


FIG. 20. *Acanthurus grammoptilus*. 245 mm. specimen, Arnhem Land, Australia. Photograph of preserved specimen by Frederick M. Bayer, United States National Museum.

The 93 mm. Arnhem Land specimen differed from the above in having fewer lines on the body, a wider pale posterior border to the caudal fin (about one-third pupil diameter in width), a narrower dark margin around the caudal spine which does not extend anterior to spine, more prominent bands in the dorsal and anal fins, and no dark brown band at the base of the dorsal fin. The color of this specimen in life (from field notes of R. R. Miller who collected the Arnhem Land specimens in 1948) was brown with a white band across the base of the caudal fin and a white posterior margin to the fin. Rust-colored spots, blotches, and wavy lines were present on the head and nape; the pectoral fin was yellowish, and there was a narrow blue margin on the anal fin.

A. C. Wheeler has kindly provided information on two of Richardson's specimens (actually half skins) of *A. grammoptilus*, the larger of which (labelled Coral Bay, Port Essington, Nov. 1840, No. 13 and bearing

British Museum No. 1843.6.15.38) is 191 mm. in standard length and evidently formed the basis for Richardson's description. Günther (1861: 335) listed these skins as types. I designate the larger as lectotype.

Richardson's description plus data from Wheeler to the effect that the larger specimen has a depth of 86 mm., 18 or 19 teeth in the jaws, inconspicuous dark streaks in the dorsal and anal fins, a dark area around the caudal peduncle spine, faint longitudinal lines on the body, no black spot at axil of dorsal or anal fins (Günther was in error in reporting these), and a pectoral fin which is darker basally leave no doubt that the species is valid and that the Arnhem Land specimens which I examined are the same.

A 204 mm. specimen in the United States National Museum from Mindoro, Philippine Islands (misidentified as *Hepatus nigrofuscus* by Fowler and Bean, 1929) appears to be *Acanthurus grammoptilus*. A color note given by Fowler and Bean (1929: 239, "Albatross" No. 6167) is as follows: "No trace of black shoulder mark. More or less orange below caudal spine. Dorsal and anal edged blue. Caudal with very narrow pale edge behind. Pectoral edge yellow." In spite of word to the contrary, there is a faint dark brown shoulder mark. It extends posteriorly from the upper edge of the gill opening a distance equivalent to about one and one-half eye diameters. The mark is not black and could have been overlooked in the field. Surrounding the caudal spine and projecting anterior to it is a reddish brown area. This area is rounded anteriorly like the comparable dark brown region in front of the caudal spine of the large Arnhem Land specimen. The outer one-fourth of the pectoral fin is pale. There is a dark brown band at the base of the dorsal fin and a narrow dark brown margin. The margin of the anal fin is dark blue.

Counts of this specimen are: D IX, 26; A III, 24; P 17; anterior gill rakers 22; posterior gill rakers 24; 17 upper teeth; 20 lower teeth (the end ones tiny).

An Arnhem Land specimen of the same length as the Philippine one provided a basis for comparison of proportional measurements (although the Philippine specimen is a male with the typical highly convex forehead and the Arnhem Land one a female). The Philippine fish has a shorter body (depth 2.2 in standard length, instead of 2.4), a shorter head (3.9 in standard length instead of 3.4), a shorter snout, a longer caudal spine, and a smaller eye. With so few specimens available and the differing sex of the two in question, it is difficult to assess these differences. Even if it could be demonstrated that the measurements of the Philippine specimen are not within the range of variability of Australian *A. grammoptilus*, the problem of deciding whether the differences are subspecific and reflect the geographic separation of the Philippines from Australia would still remain unsolved. In view of the similarity in color pattern, I prefer to regard the Philippine and Arnhem Land specimens as conspecific.

McCulloch (1918) erroneously used the name *grammoptilus* for the species *Acanthurus dussumieri*. Fowler and Bean (1929) applied the name to specimens of *A. dussumieri* and *A. xanthopterus*.

Acanthurus doreensis Cuvier and Valenciennes may be a specimen of *A. grammoptilus* with abnormal fin ray counts (see discussion of this doubtful species on page 226).

Acanthurus dussumieri Cuvier and Valenciennes

Figs. 1*h*, 2*w*, Pl. 3

Acanthurus Dussumieri Cuvier and Valenciennes (1835: 201) (Mauritius).

Acanthurus undulatus Cuvier and Valenciennes (1835: 205) (Indian Ocean); Günther (1861: 335).

Acanthurus Lamarrii Cuvier and Valenciennes (1835: 236) (Mauritius).

Acanthurus dussumieri Günther (1861: 335); Günther (1873: 112, pl. 14, fig. 3) (Hawaiian Islands); Sauvage (1891: 337) (Madagascar); Steindachner (1901: 493) (Honolulu); Jordan and Jordan (1922: 65) (Hawaiian Islands); Herre (1927: 425, pl. 14, fig. 3) (Philippine Islands); de Beaufort (1951: 155).

Acanthurus matoides Var. *b*. Playfair *in* Playfair and Günther (1866: 56) (Zanzibar).

Rhombotides Dussumieri Bleeker *in* Bleeker and Pollen (1874: 96) (Mauritius).

Rhombotides Lamarrii Bleeker *in* Bleeker and Pollen (1874: 96) (Mauritius).

Teuthis dussumieri Jordan and Evermann (1902: 357) (Formosa); Jenkins (1903: 477) (Honolulu).

Hepatus dussumieri Jordan and Evermann (1905: 390, fig. 169) (Hawaiian Islands); Jordan and Seale (1906: 351); Aoyagi (1943: 214, text fig. 54, pl. 5, fig. 14) (Riu Kiu Islands).

Teuthis grammoptilus. McCulloch (1918: 92, pl. 28) (Clarence River and Masthead Island, New South Wales).

Hepatus bariene. Fowler (1928: 270, pl. 31, fig. C) (Hawaiian Islands); Fowler and Bean (in part) (1929: 222) (Philippine Islands).

Hepatus grammoptilus. Fowler and Bean (in part) (1929: 225) (Philippine Islands and East Indies).

Acanthurus bariene. Smith (in part) (1949: 240, pl. 33, no. 613) (east coast of Africa south to Delagoa Bay).

Dorsal rays IX (one specimen found with VIII), 25 to 27; anal rays III, 24 to 26; pectoral rays 16 or 17 (usually 17); anterior gill rakers 22 to 26; posterior gill rakers 23 to 27 (see Table 20); a 48 mm. specimen has 14 upper and 14 lower teeth; a 61 mm. specimen has 16 upper and 18 lower teeth; a 94 mm. specimen has 17 upper and 18 lower teeth; a 132 mm. specimen has 19 upper and 20 lower teeth; a 325 mm. specimen has 20 upper and 22 lower teeth.

TABLE 18

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus dussumieri* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS			ANAL SOFT RAYS		
	25	26	27	24	25	26
Mauritius		3			3	
Philippine Islands	2	8	2	1	10	1
Formosa		2			2	
Okinawa		1		1		
Hawaiian Islands	4	10	3	2	10	5

Depth of body (in specimens 110 to 214 mm. in standard length) about 1.9 in standard length (nearly 2.1 in specimens greater than 300 mm. in standard length); caudal concavity varies from 14 in standard length in a 110 mm. specimen to about 7 to 9 in specimens 167 to 214 mm. in standard length to about 5 or less in specimens over 300 mm. in standard length; length of snout 4.2 to 4.6 in standard length; length of caudal spine 3 to 5 in head length (relatively longer in larger specimens); diameter of eye 3.4 in head length of 110 mm. specimen, 4 in head length of 214 mm. specimen, and 4.7 in 300 mm. specimen.

Color (in alcohol) light brown with numerous, narrow, longitudinal, slightly wavy, purplish or bluish gray lines on body; similar but broader and more irregular lines on head (these and the body lines may fade in preserved specimens); a pale brown (yellow in life) band about as wide as the pupil diameter extending anterodorsally from eye and often meeting a comparable band from other side midway in interorbital space; posterior edge of eye margined with a pale brown (yellow in life) area; caudal spine largely covered by a cream sheath; socket of caudal spine surrounded by a black area about three times as high as maximum width of caudal spine; caudal fin light brown basally and on lobes, darker in major median portion (deep blue in life) with numerous small brownish black spots; dorsal and anal fins of adults light yellowish brown (yellow in life) with traces of about two or three longitudinal dark lines posterodistally (absent in large adults); a pale bluish gray line at base of dorsal and anal fins; pectoral fins light yellowish brown; pelvic fins brown; opercular membrane black.

Acanthurus dussumieri has at times been confused with *A. xanthopterus* and *A. mata*. Adults of *A. dussumieri* may be readily recognized by the black spots on the caudal fin, the white caudal spine sheath and black area around the caudal spine, lack of a distinct series of longitudinal dark bands from base to margin of dorsal and anal fins, and the presence of purplish longitudinal lines on the body. In small specimens, however, there are longitudinal dark bands from base to margin of the dorsal and anal fins (eight in the soft dorsal of a 110 mm. specimen), the spots on the tail are less distinct or absent, and the sheath of the caudal spine is not as contrastingly pale. The lines on the body are broader and hence fewer in number; in fresh specimens the linear pattern on the body remains as the best color character for separating *A. dussumieri* from the other two species, but, as mentioned, the lines may fade on preserved specimens. The larger eye and higher gill raker counts of *A. dussumieri* are then very helpful in distinguishing this species.

I have seen specimens of *A. dussumieri* or know of definite records of this species from the east coast of Africa, islands in the Indian Ocean, Australia, East Indies, Formosa, Philippine Islands, Riu Kiu Islands and probably also southern Japan, and the Hawaiian Islands. The latter group of islands represents the sole locality for the species in Oceania. If this were ultimately found to be the true range of the species, it would be supporting evidence that pioneer fishes of the Hawaiian Archipelago arrived via the extension of the Kuroshio Current and the North Pacific Current from islands to the west of Hawaii, rather than from reefs and small islands south of Hawaii by way of a branch of the north equatorial current as postulated by Herre (1940). I do not advocate, however, that such an indication from one or even several species should form the basis for the assumption that the entire Hawaiian fish fauna had such a mode of origin.

Jordan and Seale (1906: 351) stated that *Hepatus dussumieri* is the commonest species of the genus about the Hawaiian Islands. In the same work these authors listed *Hepatus sandvicensis* (= *Acanthurus triostegus sandvicensis*) as the most abundant species of the genus about Hawaii. I concur in their latter statement. Although *Acanthurus dussumieri* is a very common species in the Hawaiian Islands, it is probably exceeded in abundance by *Acanthurus nigrofuscus* and perhaps other species as well as *Acanthurus triostegus*. It occurs both in bays and in exposed reef areas.

A. dussumieri is one of the three largest species of *Acanthurus;* it reaches a standard length of at least 400 mm.

Acanthurus xanthopterus Cuvier and Valenciennes

Fig. 2*x*, Pl. 3

Acanthurus xanthopterus Cuvier and Valenciennes (1835: 215) (Seychelles); Valenciennes (1837: pl. 71, fig. 2); Cantor (1849: 1191, pl. 4) (Pinang, Malaya).

Acanthurus matoides. Bleeker (1850*a:* 12) (Batavia, Java); Günther (1861: 330) (East Indies and Fiji Islands); Day (1865: 126) (seas of India); Playfair *in* Playfair and Günther (1866: 56) (Zanzibar) (as Variety *a*); Klunzinger (1871: 508) (Red Sea); Day (1876: 205) (seas of India); Day (1889: 141); Jordan and Snyder (1907: 217) (Hawaiian Islands); Jordan and Jordan (1922: 65) (Honolulu); Vinciguerra (1926: 567) (Sarawak, Borneo); Herre (1927: 430, pl. 16, fig. 3) (Honolulu and Philippine Islands); Herre (1936: 243) (Tahiti and Solomon Islands); de Beaufort (1951: 156) (East Indies).

Rhombotides matoides Bleeker (1863*b:* 235) (Ternate, East Indies).

? *Acanthurus matoides* Kner (1865–67) (India).

Acanthurus blochii. Günther (1873: 109, pl. 69, fig. B) (Indo-Pacific); Waite (1897: 188) (Funafuti, Ellice Islands).

Teuthis crestonis Jordan and Starks *in* Jordan (1895: 485, pl. 47) (Mazatlan, Mexico); Jordan and Evermann (1898: 1692); Jordan and Evermann (1900: pl. 256, no. 628); Gilbert and Starks (1904: 151) (Panama Bay).

Teuthis mata. Seale (1901: 107) (Guam).

Teuthis argenteus. Jordan and Fowler (1902: 553) (Okinawa and Japan).

Teuthis güntheri Jenkins (1903: 477, fig. 29) (Honolulu).

Teuthis xanthopterus Jenkins (1903: 477) (Hawaiian Islands).

Hepatus matoides. Jordan and Evermann (1905: 387) (Honolulu); Jordan and Seale (1906: 352) (Samoa); Jordan and Seale (1907: 34) (Philippine Islands).

Hepatus guntheri Jordan and Evermann (1905: 388, fig. 168).

Hepatus xanthopterus Jordan and Evermann (1905: 389) (Honolulu).

Hepatus aquilinus Jordan and Seale (1906: 353, fig. 66) (Apia, Samoa).

? *Teuthis guentheri* Bamber (1915: 482) (Red Sea).

Hepatus crestonis Snodgrass and Heller (1905: 403) (Cocos Island off Costa Rica); Fowler (1916: 411) (Panama Bay).

Acanthurus umbra. Jordan and Jordan (in part) (1922: 65) (Hawaiian Islands).

Teuthis nigrofuscus. Barnard (1927: 779) (Natal coast, Africa).

Hepatus fuliginosus. Fowler (1927: 17) (Fanning Island, Line Islands); Fowler (in part) (1928: 266, pl. 31, fig. B) (Oceania); Fowler and Bean (in part) (1929: 211) (Hawaiian Islands); Fowler (1934: 480) (Durban, Natal); Fowler (1938: 102, 202, 211, 230) (Takaroa in the Tuamotu Archipelago, Christmas and Fanning Islands, and Honolulu).

Acanthurus crestonis Meek and Hildebrand (1928: 782) (west coast of Panama).

? *Hepatus nigrofuscus*. Fowler (1928: 267) (Christmas Island, Oceania).

Hepatus elongatus. Fowler and Bean (in part) (1929: 213) (Hawaiian Islands and Samoa).

Hepatus bariene. Fowler and Bean (in part) (1929: 222) (Hawaiian Islands).

Acanthurus grammoptilus. Fowler and Bean (in part) (1929: 225) (Philippine Islands and East Indies).

Acanthurus fuliginosus. Schultz (1943: 166) (Phoenix and Samoa Islands); Smith (1949: 240, pl. 33, no. 611) (east coast of Africa south to Durban); Schultz and Woods *in* Schultz *et al*. (1953: 637) (Guam).

Teuthis fuliginosus. Fowler (1949: 102).

Dorsal rays IX (two specimens were found with VIII), 25 to 27; anal rays III, 23 to 25; pectoral rays 16 or 17 (usually 17); anterior gill rakers 16 to 24; posterior gill rakers 17 to 22 (see Table 20); a 37 mm. specimen has 12 upper and 14 lower teeth; a 59 mm. specimen has 13 upper and 15 lower teeth; a 97 mm. specimen has 15 upper and 16 lower teeth; a 126 mm. specimen has 17 upper and 18 lower teeth; a 196 mm. specimen has 18 upper and 20 lower teeth; a 320 mm. specimen has 18 upper and 21 lower teeth.

TABLE 19

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus xanthopterus* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS			ANAL SOFT RAYS		
	25	26	27	23	24	25
Durban, S. Africa		3	2		2	3
Red Sea		1			1	
Mauritius		1	1		1	1
East Indies		2	2		2	2
Philippine Islands	1	4	2	1	3	3
Solomon Islands	1	1			2	
Mariana Islands	1	5	1		7	
Gilbert Islands		1	1		1	1
Phoenix and Samoa Islands		5	2		5	2
Line Islands		3			1	2
Jarvis Island		1				1
Hawaiian Islands	2	3	2		6	1
Galapagos Islands		1				1
W. Mexico and W. Panama	2	5	1		4	4

Body depth varies from 1.95 in standard length of a 127 mm. specimen to 2.25 in a 423 mm. specimen; caudal concavity 7 in standard length of a 127 mm. specimen, 5 in standard length of a 196 mm. specimen, and 4.6 in a 320 mm. specimen; length of snout 4.8 in standard length of 127 mm. specimen, 4.95 in 196 mm. specimen, and 5.3 in 423 mm. specimen; diameter of eye 3.9 in head length of 127 mm. specimen, 4.1 in 173 mm. specimen, 4.4 in 196 mm. specimen, 4.7 in 310 mm. specimen, and 5.6 in 415 mm. specimen; length of caudal spine 5.5 in head length of 127 mm. specimen, 5 in 173 and 196 mm. specimens, 4.4 in a 310 mm. specimen; longest dorsal ray 4.4 in standard length of 127 mm. specimen, 5 in standard length of 196 mm. specimen, and 5.7 in standard length of a 320 mm. specimen.

A 196 mm. specimen of *A. xanthopterus* was speared by the author in the lagoon at Tarawa Atoll, Gilbert Islands, at a depth of 39 feet and provided the following description of the life colors: while the fish was still alive, the body color changed back and forth from uniform purplish gray to a color phase in which extremely irregular dark gray lines (about two scales in width) alternated with light blue-gray lines of about the same width; extreme posterior part of caudal peduncle and base of caudal fin dull white; remainder of caudal fin purplish gray; dorsal and anal fins yellowish gray basally, shading to dull yellow distally, with four longitudinal broad blue bands; a narrow bluish gray band at base of dorsal and anal fins; outer margin of dorsal and anal fins narrowly black; basal two-thirds of pectoral fin dusky, outer one-third yellow except extreme distal part which is hyaline; pelvic rays purplish gray, membranes dusky yellow; lower two-thirds of eye margined with diffuse yellow; a region of dull yellow extending directly anterior from eye a distance equivalent to about one eye diameter; a lesser posterior extension of dull yellow from lower corner of eye.

Preserved specimens are usually a uniform grayish brown; only occasional specimens retain the tortuous line pattern on the body. The bands in the dorsal and anal fins may fade.

The most important color characters of *A. xanthopterus*, for separating the species from *A. mata* and *A. dussumieri*, are the number of longitudinal bands in the dorsal and anal fins, the lack of narrow, nearly straight, longitudinal lines or rows of spots on the body, the lack of a black region around the caudal spine (although the region around the spine may be slightly darker than the color of the body), and (in adults) the abrupt pale color of the outer one-third of the pectoral fin. There are no small black spots on the caudal fin, no whitish caudal spine sheath, and no definite pale band which crosses or nearly crosses the interorbital space, all characteristic color markings of *A. dussumieri*.

Apart from color, *A. xanthopterus* is most distinctive in its possession of a small caudal spine, small eye (not useful in separation from *A. mata*), and low gill raker counts (see Table 20).

In Fowler and Bean (1929: 227) there is a color description of specimens bearing "Albatross" numbers 8509 and 8510 which these authors identified as *Hepatus grammoptilus*. These specimens and probably others are *Acanthurus xanthopterus*. The description of the color of specimens with the numbers 7803, 7804, and 7806, however, apply to *Acanthurus dussumieri*.

The specific names most commonly used for *A. xanthopterus* are *matoides* and *fuliginosus*. *Acanthurus matoides* Cuvier and Valenciennes is a synonym of *Acanthurus nigrofuscus*. *Acanthurus fuliginosus* Lesson was described as a uniform brown fish with a blue line on the chin. It is very unlikely that this species is the same as *A. xanthopterus* (see page 160).

Günther (1873: 109, pl. 69, fig. B) misidentified *A. xanthopterus* as *Acanthurus blochii*. *Acanthurus blochii* Cuvier and Valenciennes is probably a synonym of *Acanthurus mata* (Cuvier).

Fowler and Bean (1929: 214) placed *Hepatus aquilinus* Jordan and Seale in the synonymy of *Hepatus elongatus*. I examined the type of *H. aquilinus*, and it is a moderately large specimen of *Acanthurus xanthopterus*.

I am unable to distinguish *Acanthurus crestonis* (Jordan and Starks) of the western coast of Mexico and Central America from *Acanthurus xanthopterus;* thus I have placed the former in the synonymy of the latter.

The type of *Acanthurus xanthopterus*, a 162 mm. specimen, is in the Paris Museum (No. 162).

A. xanthopterus is probably the largest species of *Acanthurus*. It may exceed 500 mm. in standard length. It occurs commonly in bays and lagoons, but may also be taken in outer reef areas. At least in the adult stage it appears to be more characteristic of deeper water than most surgeon fishes. Trap fishermen in the Hawaiian Islands refer to the species as deep water *pualu;* they call *A. mata* merely *pualu.*

A. xanthopterus is a wide-ranging species. It is known from East Africa to West Mexico.

Acanthurus mata (Cuvier)

Figs. 1*d*, 2*y*, Pl. 3

? *Chaetodon nigricans*. Bloch (1787: 184, pl. 203).

? *Acanthurus nigricans*. Bloch and Schneider (1801: 211) (Arabian Sea).

? *Acanthurus nigricans*. Rüppell (1828: 57) (Red Sea).

Chaetodon meta Cuvier (1829: 224) (after Russell, error for *mata*).

Acanthurus mata Cuvier and Valenciennes (1835: 202); Schultz and Woods *in* Schultz *et al*. (1953: 639) (Marshall Islands).

TABLE 20

VARIATION IN GILL RAKER COUNTS OF SPECIMENS OF *Acanthurus dussumieri*, *Acanthurus xanthopterus*, AND *Acanthurus mata* FROM DIFFERENT LOCALITIES

SPECIES AND LOCALITY	ANTERIOR GILL RAKERS											POSTERIOR GILL RAKERS										
	16	17	18	19	20	21	22	23	24	25	26	17	18	19	20	21	22	23	24	25	26	27
A. dussumieri																						
Mauritius									1										1			
Philippine Islands							1	2	1	1								1	2		2	
Hawaiian Islands								3	3		1								2	3	1	1
A. xanthopterus																						
Durban, S. Africa					1				1						1	1						
Red Sea			1											1								
Mauritius		1					1					1			1							
Philippine Islands		1	4	1										1	3	2						
Solomon Islands				1			1							1	1							
Mariana Islands	1	2	3											4	1	1						
Gilbert Islands			1			1								1	1							
Phoenix and Samoa Islands		1	3										1		1		1					
Line Islands		2		1											1	2						
Hawaiian Islands		1	3	3	1	1	1					1	1	2	4	2						
Galapagos Islands						1									1							
W. Mexico and W. Panama		1	2		2		1						1	3	1	1						
A. mata																						
Durban, S. Africa					1												1					
Mariana Islands						1														1		
Marshall Islands					1	1													1	1		
Wake Island							2													1		
Tuamotu Archipelago					1																1	
Hawaiian Islands					2	4	9	3		1								5	5	8	1	

Acanthurus rasi Cuvier and Valenciennes (1835: 203) (Pondichéry, India).

? *Acanthurus Blochii* Cuvier and Valenciennes (1835: 209) (Mauritius).

Acanthurus nigro-fuscus. Günther (1861: 331) (Ceylon and Ambon, East Indies).

Acanthurus blochi Streets (1877: 68) (Harbor of Honolulu).

Acanthurus umbra. Jordan and Jordan (in part) (1922: 65) (Hawaiian Islands); Schultz (1943: 165) (Tutuila Island, Samoa Islands).

? *Hepatus mata* Fowler (1928: 267) (Society Islands).

Hepatus bariene. Fowler and Bean (in part) (1929: 222) (Philippine Islands).

? *Teuthis mata* Fowler (1949: 102).

Acanthurus sp. two Harry (1953: 150) (Raroia, Tuamotu Archipelago).

Acanthurus lineolatus. Smith (in part) (1949: 240, pl. 33, no. 609) (east coast of Africa south to Durban).

Dorsal rays IX, 25 to 27; anal rays III, 24 or 25; pectoral rays 17; anterior gill rakers 20 to 25; posterior gill rakers 23 to 26 (see Table 20); a 47 mm. specimen has 14 upper and 14 lower teeth; an 84 mm. specimen has 16 upper and 16 lower teeth; a 101 mm. specimen has 16 upper and 18 lower teeth; a 153 mm. specimen has 18 upper and 19 lower teeth; a 203 mm. specimen has 18 upper and 20 lower teeth; a 247 mm. specimen has 20 upper and 20 lower teeth.

TABLE 21
VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus mata* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS			ANAL SOFT RAYS		
	25	26	27	23	24	25
Durban, S. Africa		1				1
Mariana Islands	1				1	
Marshall Islands	1	1			2	
Wake Island			1			1
Tuamotu Archipelago		1			1	
Hawaiian Islands	4	9	2	1	12	2

Depth of body 1.9 to 2.1 in standard length; caudal concavity varies from 10 in standard length of a 151 mm. specimen to 8.2 in a 191 mm. specimen, and to 6.2 in a 292 mm. specimen; length of snout 4.3 to 4.5 in standard length; eye diameter 3.1 in head length of 47 mm. specimen, 4.2 in head length of 151 mm. specimen, and 5 in head length of 292 mm. specimen; length of caudal spine 3 to 4.4 in head length.

Color (in alcohol) brown (the rows of small spots on the sides are usually lost in preservative); base of caudal fin abruptly pale, remainder of fin brown (dark blue in life with about six indistinct, vertical, slightly wavy, dark lines); dorsal fin with eight or nine narrow longitudinal dark bands, and anal fin with five or six similar bands (the bands in the fins are often not visible in preserved specimens); pectoral fins entirely brown; pelvic fins brown; dark brown to black region around caudal spine about twice as high as maximum width of spine; the most prominent marking on head in life is an elongate yellow spot (about half the size of the eye) which extends posteriorly and slightly upward from lower edge of eye; this is usually lost in preservative.

A. mata is distinct from *A. xanthopterus* in having eight or nine instead of four or five longitudinal dark bands in the soft portion of the dorsal fin, a uniform brown pectoral fin (the outer one-third of the pectoral fin of *A. xanthopterus* is pale), a more definite dark area around the caudal spine, a larger caudal spine, and higher gill raker counts.

Adult *A. mata* may be distinguished from adult *A. dussumieri* by lacking black caudal spots, white caudal spine sheath, and a pale transverse band on the interorbital, and having numerous longitudinal bands in the dorsal and anal fins. Fresh specimens of subadult *mata* may be best distinguished from *A. dussumieri* of about the same size (which may have eight or nine bands in the dorsal fin and five or six in the anal like *mata*) by the linear pattern of the body. Lines of small pale spots occur on *A. mata;* the lines on the body of *A. dussumieri* are unbroken. On preserved specimens the body color of either species may be uniform brown; the larger size of the eye of *dussumieri* is then the best means of separation.

When viewed underwater, *A. mata* appears almost black except for the base of the caudal fin which is usually white. The degree of whiteness of the caudal band is variable. The band is generally dull white or gray on captive fish. This appears to be true of all of the species of *Acanthurus* which have a white or light gray caudal base.

The blue and yellow colors of specimens of *A. mata* collected from bays were noticeably duller than these colors on specimens from clear outer reef areas.

There is no type specimen of *Acanthurus mata*. The name and description originated with the prelinnaean author Russell whose work I have not seen. Cuvier (1829: 224) cited Russell when he listed *Chaetodon meta* among the surgeon fishes in his Règne Animal. This appears to be an error for *mata*, for all subsequent authors, some of whom have referred to Russell, have spelled the name *mata*. Cuvier and Valenciennes (1835: 202) gave a brief description based on Russell. Their reference to the similarity to *Acanthurus dussumieri*, the dark body color with blue on the head and elsewhere, and a size up to 18 inches constitutes the principal basis for my calling the species, as here defined, *Acanthurus mata*.

Schultz and Woods (1953: 640) correctly assigned the name *Acanthurus mata* to two large specimens (280 and 310 mm.) from the northern Marshall Islands. These authors proposed that the name *mata* be restricted to Plate 48, Figure 1 of Day (1876); however, this figure appears to be *Acanthurus nigrofuscus* (Forskål).

I have been unable to identify or can only tentatively identify many of the records in the literature which may be *A. mata* because of insufficient descriptive information. To my knowledge, the species has never been figured. Most of the unquestioned names in my synonymy for the species are based on the examination of specimens. *Acanthurus blochi* of Streets (1877: 68), for example, are small specimens of *A. mata*. Fowler and Bean (1929: 246) were in error in considering these as *Hepatus glaucopareius*.

Although the color seems a little different, the species from Africa identified as *Acanthurus lineolatus* by Smith (1949: 240, pl. 33, fig. 609) is probably *A. mata*. A 71 mm. specimen kindly loaned by Smith proved to be *Acanthurus bleekeri*, however.

Acanthurus monroviae Steindachner
Figs. 2*z*, 21

Acanthurus phlebotomus. Troschel (*non* Cuvier and Valenciennes) (1866: 227) (Cape Verde Islands).

Acanthurus Monroviae Steindachner (1876: 160) (Monrovia, Liberia).

Acanthurus chirurgus. Peters (1876: 246) (Victoria, Cameroon, West Africa).

Acanthurus monroviae Steindachner (1895: 18) (mouth of Messurado River and Cape Mount, Liberia); Metzelaar (1919: 256) (Senegal Coast, West Africa).

Teuthis munroviae Gill (1896: 188) (error for *monroviae*).

Dorsal rays IX, 25 to 27; anal rays III, 24 to 26; pectoral rays 17; anterior gill rakers 16 or 17; posterior gill rakers 16; an 88 mm. specimen has 12 upper and 14 lower teeth; a 192 mm. specimen has 18 upper and 18 lower teeth. These counts and the measurements given below were obtained from two specimens from Liberia which are in the United States National Museum.

Depth of body 2.0 (in 192 mm. specimen) to 2.2 (in 88 mm. specimen) in standard length; caudal concavity 7.6 (in 192 mm. specimen) to 10.4 (in 88 mm. specimen) in standard length; diameter of eye 3.5 (in 88 mm. specimen) to 4.0 (in 192 mm. specimen) in head length; length of snout 4.9 to 5.2 in standard length; length of longest dorsal

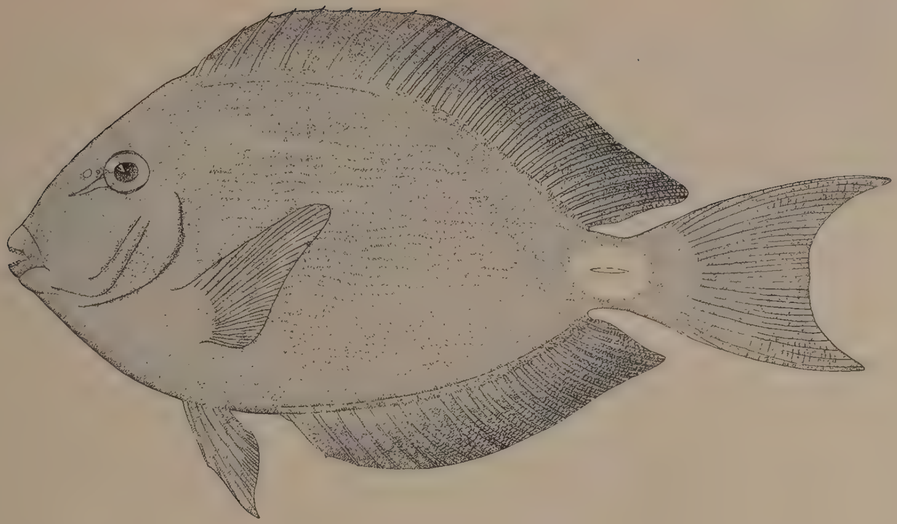


FIG. 21. *Acanthurus monroviae*. 192 mm. specimen, Liberia. Drawing by L. B. Isham, United States National Museum.

ray 4.9 to 5.1 in standard length; length of pectoral fin 3.4 (in 88 mm. specimen) to 3.6 (in 192 mm. specimen) in standard length; length of caudal spine 4.5 to 5.7 in head length.

Color (in alcohol) of 88 mm. specimen brown with a white area (in height slightly less than diameter of eye) around caudal spine; about 15 narrow, dark, undulating lines on side of body; opercular membrane very dark brown; area around edge of upper limb of preopercle very dark brown; median fins very dark brown except extreme margin of central part of caudal fin which is pale; pectoral fin rays dusky except for outer part of lower 11 rays which are pale; pectoral membranes pale; pelvic fins very dark brown. The 192 mm. specimen differs in color in having more numerous and less conspicuous lines on the body, a relatively larger pale area around the caudal spine (in height almost one-third the head length), black median fins except base of dorsal and anal which are brown, and the margin of the preopercle only slightly darker than the rest of the head.

The pale spot around the caudal spine was described as yellow in life. Peters (1876) mentioned a blue border around this yellow area. Both Peters and Steindachner described the lines on the body as blue.

Fowler (1936: 912) erroneously synonymized this species with *Hepatus hepatus* (= *Acanthurus chirurgus*).

Acanthurus monroviae is known only from West Africa.

Acanthurus coeruleus Bloch and Schneider

Figs. 2*aa*, 22

Acanthurus Coeruleus Bloch and Schneider (1801: xxxviii, 214) (Carolina and Havana).

Acanthurus Broussonnetii Desmarest (1823: 26, pl. 3, fig. 1) (Cuba).

Acanthurus caeruleus Cuvier and Valenciennes (1835: 175) (Martinique, Puerto Rico, and Santo Domingo); Castelnau (1855: 25) (Bahia, Brazil); Günther (1861: 336) (West Indies, Caribbean Sea, and Bahia); Poey (1868: 355) (Cuba); Beebe and Tee-Van (1928: 184) (Port-au-Prince Bay, Haiti);

Breder (1929: 221); Beebe and Tee-Van (1933: 179) (Bermuda); Longley and Hildebrand (1941: 155) (Tortugas, Florida).

Acanthurus coeruleus Storer (1846: 112); Lütken (1880: 609, pl. 5, fig. 3) (Antilles); Jordan and Gilbert (1882: 617); Meek and Hildebrand (1928: 782) (Atlantic coast of Panama).

Acanthurus violaceus Castelnau (1855: 25).

Acanthurus brevis Poey (1860: 207) (Cuba); Poey (1868: 355).

Acronurus caeruleatus Poey (1875: 69, pl. 3, figs. 15 to 17 of developing scales) (Cuba).

Acanthurus nigricans. Goode (1876: 41) (Bermuda).

Teuthis coeruleus Meek and Hoffman (1884: 228); Evermann and Marsh (1902: 253, pl. 38) (Puerto Rico).

Teuthis helioides Barbour (1905: 127, pl. 3) (Bermuda).

Hepatus caeruleus Fowler (1916: 405) (Colon, Panama).

Hepatus pawnee Breder (1927: 73, fig. 32) (Glover Reef, British Honduras).

Teuthis caeruleus Nichols and Breder (1927: 134) (New York).

Acanthurus heliodes Beebe and Tee-Van (1933: 179) (error for *helioides*) (Bermuda).

Teuthis (*Rhomboteuthis*) *coeruleus* Fowler (1944*a:* 109, pl. 13, upper left fig.) (Courtown Keys, Caribbean Sea).

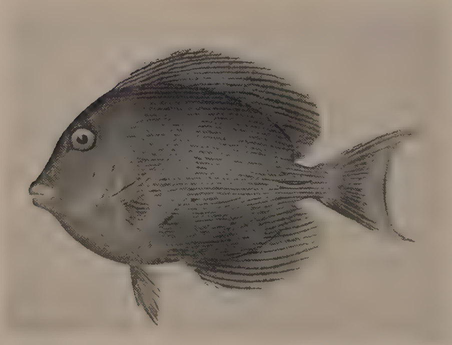


FIG. 22. *Acanthurus coeruleus* (after Jordan and Marsh, 1902).

Acanthurus hepatus. Carvalho (1952: 115, fig.) (Trinidad).

Dorsal rays IX, 26 to 28; anal rays III, 24 to 26; pectoral rays 16 or 17; anterior gill rakers 13 or 14; posterior gill rakers 13 (raker counts from specimens from Bermuda to Brazil); a 38 mm. specimen has 8 upper and 10 lower teeth; an 82 mm. specimen has 10 upper and 12 lower teeth; 90 and 115 mm. specimens have 12 upper and 14 lower teeth; a 235 mm. specimen has 14 upper and 16 lower teeth.

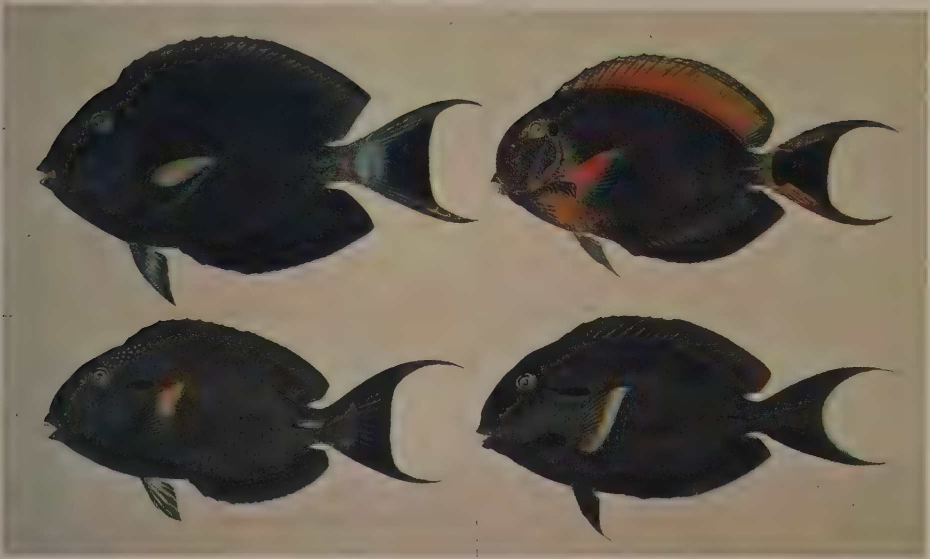
TABLE 22

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus coeruleus* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS			ANAL SOFT RAYS		
	26	27	28	24	25	26
Bermuda		2	1		2	1
Florida	1		2	1	2	
West Indies	3	11	2	2	11	3
Brazil		1	1		1	1

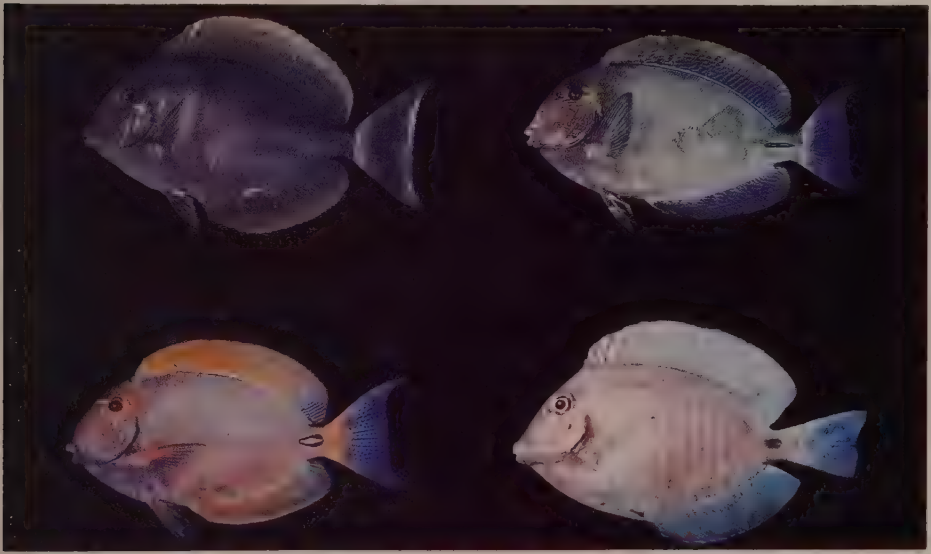
Depth of body 1.7 in standard length; caudal concavity varies from 11.7 in standard length in an 82 mm. specimen to 7.7 in a 115 mm. specimen, to 5.3 in a 178 mm. specimen, and 5.1 in a 235 mm. specimen; caudal spine 6.5 in head length of an 82 mm. specimen, 3.7 in 235 mm. specimen; length of pectoral fin 2.8 to 2.95 in standard length; diameter of eye 3 in head length of an 82 mm. specimen and 4.5 in head length of a 235 mm. specimen.

Color (in alcohol) grayish brown with alternating dark and light, slightly irregular, longitudinal lines on body (the light lines are about three times as broad as the dark); lines on dorsal part of body angle upward to dorsal fin; caudal fin grayish brown with a very narrow pale posterior margin and a dark submarginal band about four times as broad as the pale margin; dorsal fin with about seven dark longitudinal bands in the spinous portion and nine in the soft portion; anal fin with



Acanthurus fowleri. *Acanthurus bariene.*
Acanthurus maculiceps. *Acanthurus gahhm.*

From paintings of the Philippine "Albatross" Expedition, 1909, in the Division of Fishes, United States National Museum. Reproduced by courtesy of Leonard P. Schultz.



A. xanthopterus, 174 mm. specimen, Hawaiian Islands. *A. mata*, 269 mm. specimen, Hawaiian Islands.
A. dussumieri, 255 mm. specimen, Hawaiian Islands. *A. chirurgus*, Florida (pale phase).

(Note scratches and reflections on figures.)

about five longitudinal dark bands; margins of dorsal and anal fins dark brown; pectoral fins pale; pelvic fins dark brown; no dark area around caudal spine; sheath of caudal spine pale.

A 125 mm. specimen speared by the writer at Nassau, Bahamas, provided the following color note: body purplish gray with 26 irregular dark gray longitudinal lines; dorsal and anal fins bright blue with orange-brown longitudinal bands; caudal fin blue, shading to yellowish gray in center; pectoral fins clear yellow; pelvic fins blue; sheath of caudal spine white. Some specimens observed underwater had three vertical pale bars on the body.

Townsend (1929: 19, pl. 21) described and figured three color phases of this species from aquarium observations, a blue, a blue with three or four pale vertical bars, and a creamy white with blue margins on the fins. The latter phase was seldom seen until evening when the fish settled toward a white sand bottom. Longley (1941: 155) observed that the species was very light over a pale sandy bottom.

Longley also observed that the young are clear yellow, and he correctly referred *Teuthis helioides* Barbour to the synonymy of *Acanthurus coeruleus*. He stated that specimens up to 100 or 125 mm. in length may be yellow. His length measure is probably total length. The longest yellow specimen which I have seen is the type of *Teuthis helioides* in the Museum of Comparative Zoology (No. 29053). It is 77 mm. in standard length. The size at which the blue-gray color replaces the yellow is variable. I speared a 31 mm. specimen at Nassau which was blue except for the middle of the caudal fin which was yellow.

The largest specimen of *A. coeruleus* seen by me is a 235 mm. one from Bermuda. Another from Bimini is 234 mm. in standard length.

Lütken (1880: pl. 5, figs. 3, 4, and 5) figured the postacronurus, acronurus, and a 5.7 mm. postlarval specimen of *A. coeruleus*. The postacronurus has three vertical pale bands on the body.

Hepatus pawnee Breder (1927: 73, fig. 32) is apparently the acronurus of *A. coeruleus*, judging from the deep body and the fin ray counts D IX, 27 and A III, 25. It was taken at a night light at Glover Reef, British Honduras.

Fowler (1944*a:* 109) proposed the subgenus *Rhomboteuthis* for *A. coeruleus*. As previously discussed (Randall, 1955*b*), this does not seem justified.

Longley (1941: 155) pointed out that *A. coeruleus* is seen more often well above the bottom than the other two surgeon fishes commonly seen in Florida waters, *A. chirurgus* and *A. bahianus*. He stated that the food of *A. coeruleus* is wholly algal like that of *A. chirurgus* and *A. bahianus* but contains less sand and bottom debris than that of the latter two species. This is consistent with the structure of the stomach of these three species. *A. coeruleus* has a thin-walled stomach, whereas the other two species have heavy-walled, gizzard-like stomachs. Breder and Clark (1947: 295, fig. 1) described the morphology of the digestive tract of *A. coeruleus*.

Acanthurus chirurgus (Bloch)

Figs. 1*b*, 2*bb*, Pl. 3

Chaetodon chirurgus Bloch (1787: 204, pl. 208) (Martinique).

Acanthurus Chirurgus Bloch and Schneider (1801: xxxviii, 214) (Caribbean Sea).

Acanthurus Hepatus. Bloch and Schneider (in part) (1801: 211) (America and Bahama Islands).

Acanthurus chirurgus Lacépède (1802: 546); Cuvier and Valenciennes (1835: 168) (Martinique, Puerto Rico, Cuba, and Brazil); Storer (1846: 112); Günther (in part) (1861: 329) (Caribbean Sea, West Indies, Venezuela, and Brazil); Günther (1869: 238) (St. Helena); Goode (1876: 42) (Bermuda); Jordan and Gilbert (1882: 617); Metzelaar (1919: 256) (both sides of Atlantic).

Acanthurus phlebotomus Cuvier and Valenciennes (1835: 176, pl. 287) (Martinique, Brazil, Havana, and New York); Storer (1846: 111); Poey (1868: 355) (Cuba).

Acanthurus chirurgicus Castelnau (1855: 24) (Bahia, Brazil).

Acanthurus nigricans. Jordan and Gilbert (1882: 941).

Teuthis hepatus. Meek and Hoffman (1884: 229); Jordan and Evermann (1898: 1691); Evermann and Marsh (1902: 254) (Puerto Rico); Nichols and Breder (1927: 134) (New York); Gudger (1929: 196) (Tortugas, Florida); Fowler (1944*a:* 110, pl. 13, right hand figs.) (Courtown Keys, Caribbean Sea).

Hepatus hepatus. Fowler (1916: 403) (Colon, Panama); Fowler (1936: 912, fig. 385) (West Africa).

Acanthurus hepatus. Meek and Hildebrand (1928: 784) (Atlantic coast of Panama); Beebe and Tee-Van (1928: 185) (Port-au-Prince Bay, Haiti); Breder (1929: 221); Beebe and Tee-Van (1933: 181, col. pl. 4, incorrectly labelled *Acanthurus caeruleus*) (Bermuda); Longley and Hildebrand (1941: 156) (Tortugas, Florida).

Dorsal rays IX, 24 or 25; anal rays III, 22 or 23; pectoral rays 16 or 17; anterior gill rakers 16 to 19; posterior gill rakers 15 to 18 (raker counts from West Indian specimens); 32 mm. and 54 mm. specimens have 10 upper and 12 lower teeth; a 140 mm. specimen has 16 upper and 18 lower teeth; a 184 mm. specimen has 18 upper and 20 lower teeth.

TABLE 23

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus chirurgus* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS		ANAL SOFT RAYS	
	24	25	22	23
Massachusetts	1	1	1	1
Bermuda		1	1	
Florida		2		2
West Indies	9	22	10	21
Brazil	1		1	

Depth of body about 2 in standard length; caudal fin emarginate (nearly truncate in young), caudal concavity about 14 to 18 in standard length; length of caudal spine 5 in head length of a 54 mm. specimen, 3.5 in a 165 mm. specimen; length of pectoral fin 3 in standard length; diameter of eye 2.9 in standard length of a 54 mm. specimen, 3.8 in a 184 mm. specimen.

Color (in alcohol) brown, usually with 10 to 12 long vertical dark brown bars visible on side of body; caudal spine enclosed in a very dark brown area, the height of which is about three times the maximum width of the spine; no definite white posterior margin to caudal fin (extreme tips of caudal rays pale, resulting in a very narrow, irregular, white margin); dorsal fin with nine diagonal dark bands in spinous portion (two to seven on each interspinous membrane) and nine or ten in soft portion (these mostly longitudinal); anal fin with four similar bands (the bands in the fins often fade completely in preservative); margins of dorsal and anal fins narrowly dark brown; outer one-third of pectoral fin pale in adult specimens; membranes of pelvic fins very dark brown; opercular membrane black.

The color photograph of *A. chirurgus* from which Plate 3 was reproduced was taken of a specimen collected by the author in a sandy region at Soldier Key, Florida. It is in a pale color phase. Over a dark substrate the species is usually brown as shown in the two lower figures of plate 22 in Townsend (1929). Longley (1941: 156) described the color phases of this species in detail.

The largest specimen seen by me measured 228 mm. It was taken at Panama.

A. chirurgus is probably the most wide-ranging species of *Acanthurus* in the Atlantic, apparently occurring on the coast of West Africa as well as the entire tropical and subtropical regions of the West Atlantic. Its extension into cooler waters of the northeast United States (such as Massachusetts) is probably a result of transport of the larvae by the Gulf Stream from more southern regions where resident populations are established. The specimens which I have seen from such northern localities have all been juveniles or subadults. The same applies to specimens of *A. coeruleus* and *A. bahianus*. Breder (1929: 222) stated that *A. chirurgus* is the most common species of the family on the Atlantic coast of the United States.

Townsend (1929: 19) reported that this fish lives well in captivity. Although largely herbivorous, specimens were kept as long as five years in the New York Aquarium on a fish and clam diet varied occasionally with seaweed.

Longley (1941: 156) pointed out, and I have verified his observation, that *Acanthurus chirurgus* often swims in small schools with *A. bahianus*.

After first doubting Longley's placing of *Hepatus pawnee* in the synonymy of *Acanthurus hepatus* (= *Acanthurus chirurgus*), Breder (1949: 296) decided he was correct. I believe, however, that *H. pawnee* as figured by Breder (1927: fig. 32) is the acronurus of *Acanthurus coeruleus*. If the fin ray counts D IX, 27; A III, 25 are correct, no other conclusion could be drawn (see Tables 22 to 24).

Many recent authors have applied the name *Acanthurus hepatus* to the species *Acanthurus chirurgus*. Three different species of surgeon fishes of five prelinnaean authors were cited by Linnaeus (1766: 507) under the name *hepatus*. Cuvier and Valenciennes were the first to restrict the name. They used it for the East Indian species of Seba (1734: 104, pl. 33, fig. 3) which is now recognized as the single species in the genus *Paracanthurus*.

Acanthurus bahianus Castelnau

Figs. 1*c*, 2*cc*, 23

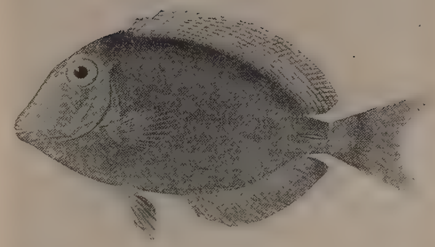


FIG. 23. *Acanthurus bahianus* (after Jordan and Evermann, 1900, retouched).

Acanthurus bahianus Castelnau (1855: 24, pl. 11, fig. 1) (Bahia, Brazil); Meek and Hildebrand (1928: 783) (Atlantic coast of Panama); Beebe and Tee-Van (1928: 184) (Port-au-Prince Bay, Haiti); Breder (1929: 222); Beebe and Tee-Van (1933: 180) (Bermuda); Longley and Hildebrand (1941: 156) (Tortugas, Florida).

Acanthurus tractus Poey (1860: 208) (Cuba); Poey (1868: 356); Jordan and Gilbert (1882: 941).

Acanthurus chirurgus. Günther (in part) (1861: 329) (Caribbean Sea and Brazil).

Acronurus nigriculus Poey (1875: 69, pl. 3, figs. 18 and 19 of scales and caudal fin) (Cuba).

Teuthis tractus Meek and Hoffman (1884: 229).

Teuthis bahianus Jordan and Evermann (1898: 1693) (Key West, Florida and Bahia, Brazil); Jordan and Evermann (1900: pl. 256, no. 629); Evermann and Marsh (1902: 254, fig. 70) (Puerto Rico); Nichols and Breder (1927: 135) (Woods Hole); Gudger (1929: 197) (Tortugas, Florida); Fowler (1944*a:* 110, pl. 13, lower left fig.) (Courtown Keys, Caribbean Sea).

Hepatus bahianus Fowler (1916: 405) (Colon, Panama).

Teuthis coeruleus. Gudger (1929: 196) (Tortugas, Florida).

Dorsal rays IX, 23 to 26; anal rays III, 21 to 23; pectoral rays 15 to 17 (usually 16); anterior gill rakers 20 to 22; posterior gill rakers 17 to 19 (raker counts from West Indian specimens); a 55 mm. specimen has 12 upper and 12 lower teeth; an 85 mm. specimen has 12 upper and 14 lower teeth; a 100 mm. specimen has 14 upper and 16 lower teeth; a 170 mm. specimen has 14 upper and 16 lower teeth.

Depth of body about 2 in standard length; caudal concavity varies from 13.5 in a 68 mm. specimen to 8.3 in a 124 mm. specimen to 4.6 in a 170 mm. specimen; length of caudal spine 3.5 in head length of a 105 mm. specimen, 2.8 in a 155 mm. specimen; length of pectoral fin 3 in standard length of a 105 mm. specimen, 3.5 in standard length of a 155 mm. specimen; diameter of eye 3 in head length of a 105 mm. specimen, 3.5 in 155 mm. specimen.

TABLE 24

VARIATION IN FIN RAY COUNTS OF SPECIMENS OF *Acanthurus bahianus* FROM DIFFERENT LOCALITIES

LOCALITY	DORSAL SOFT RAYS				ANAL SOFT RAYS		
	23	24	25	26	21	22	23
Massachusetts	1					1	
Bermuda			2				2
Florida		2	1		1	2	
West Indies	2	19	8	1	2	21	7
Brazil		3	1			3	1

Color (in alcohol) brown, with or without narrow, faint, longitudinal lines on body; caudal fin with a definite white posterior margin which is broader in median part of fin (in maximum width about one-third the diameter of the pupil in adults, proportionally wider in young); base of caudal fin usually paler than rest of body; 9 to 11 narrow longitudinal dark lines usually visible in dorsal fin; anal fin with about four similar bands, but these usually fade in preservative; margins of dorsal and anal fins narrowly dark brown; pectoral fins light brown; membranes of pelvic fins dark brown; margin of caudal spine socket narrowly black; sheath of caudal spine dark brown; opercular membrane black.

Color in life of a 121 mm. specimen collected by the author at Bache Shoal, Florida: body light yellowish brown with faint pale greenish gray longitudinal lines (ventrally the body is dull brassy yellow and the lines are light grayish blue); throat pale grayish blue; caudal fin olive-yellow, the posterior margin bluish white; margin of dorsal and anal fins bright blue; dorsal fin with alternating lengthwise bands of dull orange and light bluish green; anal fin with alternating grayish blue and dark gray bands; pectoral rays dusky orange, membranes hyaline; pelvic rays pale blue, membranes black; a narrow violet area surrounding caudal spine; upper one-fourth of opercular membrane purple, lower three-fourths black; a purplish gray area adjacent to posterior edge of eye, this region crossed by six to seven narrow yellow lines which radiate from eye; a few small yellow spots below eye; a short blue line anterior to eye.

Longley (1941: 157) stated that this species is golden brown on the open reef and matches very well the dominant color of the algae on which it may be seen cropping all day long. Like *A. chirurgus*, it readily displays a very pale color phase.

The largest specimen seen by me measures 170 mm. in standard length. It was collected at Cuba.

I examined the type specimen of *Acanthurus tractus* Poey at the Museum of Comparative Zoology. Without doubt it is *A. bahianus*.

A. bahianus appears to be confined to the western Atlantic. It is known from Brazil to Massachusetts.

DOUBTFUL SPECIES

Acanthurus doreensis Cuvier and Valenciennes

Acanthurus doreensis Cuvier and Valenciennes (1835: 220) (Dorey Harbor, New Guinea); Bleeker (1850*a:* 5); Günther (1861: 332); Macleay (1883: 354).

Rhombotides doreensis Bleeker (1878: 51).

Hepatus doreensis Fowler (1928: 268); Jordan and Seale (1906: 351).

To my knowledge the species is known only from the type (No. A 7099) in the Paris Museum. It was described by Valenciennes as brown with the posterior part of the pectoral yellowish and the terminal border of the caudal fin with a white margin. The length was given as 8 inches. The fin ray counts D IX, 28 and A III, 20 are most distinctive, and on the basis of these Bleeker, Günther, Macleay, and Fowler all regarded the species as valid. Jordan and Seale, however, suggested that it might be the young of *Hepatus nigricans* (= *Acanthurus gahhm*) or *H. elongatus* (= *A. nigrofuscus*), and that the anal rays of the specimen were miscounted. These authors are probably in error in considering it a juvenile, for an eight-inch specimen of any known species of *Acanthurus* would be an adult or near-adult.

L. Bertin of the Paris Museum has kindly supplied the following information on the type. It is 166 mm. in standard length, has a caudal concavity of 20 mm., and 16 upper and 18 lower teeth. No black bar can be perceived on the shoulder region of the specimen. There are 28 dorsal soft rays and 20 anal soft rays. "Aucun doute à cet égard."

Of the known species of *Acanthurus*, *A. doreensis* is closest to *A. grammoptilus* Richardson. The number of teeth in the jaws, shape of the caudal fin, yellowish outer part of the pectoral fin, white posterior margin of the caudal fin, and lack of a definite mark on the shoulder region are characteristic of the latter species. The usual soft fin ray counts of D 26 and A 24 of *A. grammoptilus* do not seem to offer any possibility, however, even in the extreme range of normal variability, of ever being D 28 and A 20. In fact, the latter combination of counts can be found in no species of *Acanthurus*. It would seem, therefore, that *A. doreensis* is either an abnormal specimen of *A. grammoptilus* or is a good species. Decision on the matter should await the collection of further specimens.

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*PISCIVOROUS GASTROPODS OF THE GENUS CONUS**

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Many marine snails are known to feed saprophytically on dead fishes.[1, 2] The observations reported here are believed to represent the first known instances of the attacking, killing, and eating of live fishes by gastropod mollusks. It will also be shown that live fishes are the dominant and apparently exclusive food of one, and probably both, species of *Conus* to be discussed. This paper thus reports on an ecological niche not previously known to be occupied by gastropods.

Feeding Mechanism.—Members of the family Conidae (Prosobranchiata: Stenoglossa) are predacious and feed by injecting a venom into the prey organism with a detachable, dartlike radula tooth (Fig. 1). There are but few reports of the observation of this process in the living animal. Most of our knowledge has been gained from anatomical studies of fixed specimens[3] and from accounts of human injuries inflicted by these snails.[4] A more complete account of the feeding process, based on current studies of the ecology of the group, will be published elsewhere.

Food in Nature.—Fish remains were first discovered in the alimentary tract of a specimen of *Conus striatus* L. from Hawaii dissected by Kondo.[4] Additional fish remains were found in several specimens of this species from Hawaii and Guam dissected by the present author.[5] In each case, however, remains were insufficient to permit identification of the fishes, even to family. No other types of prey organism were found in alimentary tracts of *C. striatus.*

No previous reports are known of fish remains in *C. catus* Bruguière. Examination of alimentary tracts of twenty specimens of this species collected by the author in Hawaii revealed bones, otoliths, scales, and other remains of fishes in nine. The alimentary tract of one contained a discharged radula tooth, and those of the remaining ten specimens were empty.

Three of the fishes were identified as the blenny *Istiblennius gibbifrons* Quoy and Gaimard. Two others are probably *Bathygobius fuscus* Rüppell. The remains of four were insufficient to permit identification.

Feeding of C. striatus in the Laboratory.—Specimens of *C. striatus* have been fed *Kuhlia sandvicensis* Steindachner, *I. gibbifrons* Quoy and Gaimard, and *Entomacrodus marmoratus* Bennett in the laboratory.

Abbreviations: b = barbs; k = terminal knob; l = ligament; m = mouth; p = proboscis; rt = position of radula tooth within proboscis; s = siphon; sh = shell; t = tentacle, which bears the eye.

FIG. 1.—Photograph of radula tooth of *Conus striatus.* Length of tooth, excluding ligament, 10.6 mm.

FIG. 2.—Drawing of *C. striatus* with proboscis extended. External organs labeled.

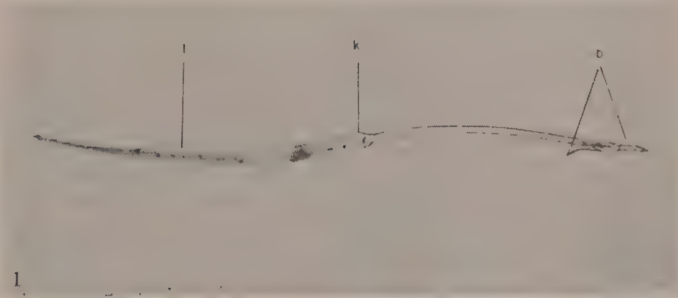
FIG. 3.—Feeding process in *C. striatus.* Proboscis is extended toward fish (*Entomacrodus marmoratus*).

FIG. 4.—Feeding process in *C. striatus.* Proboscis in contact with fish.

FIG. 5.—Feeding process in *C. striatus.* Fish is stung and impaled on ejected radula tooth.

FIG. 6.—Feeding process in *C. striatus.* Fish is drawn into distended buccal cavity.

FIG. 7.—Feeding process in *C. striatus.* Engulfment is complete.



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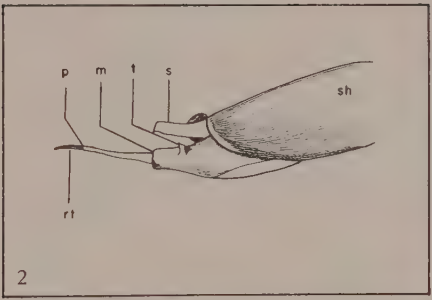

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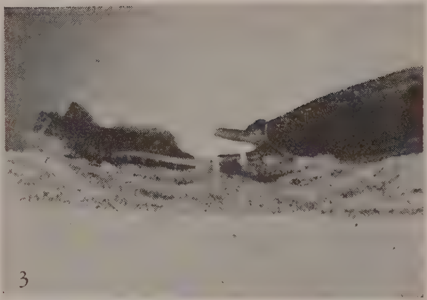

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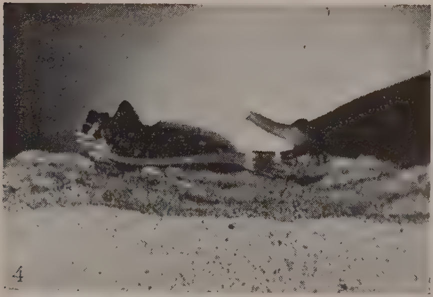

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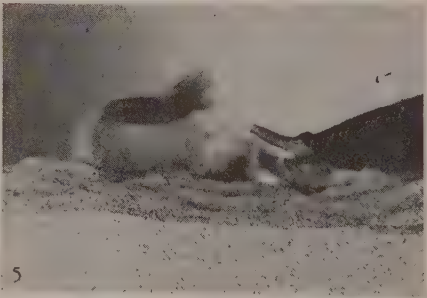

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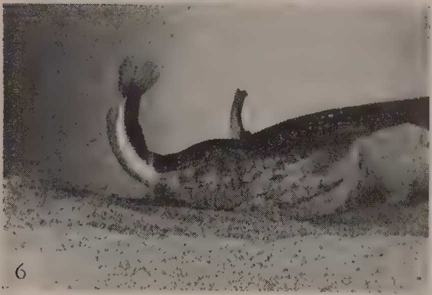

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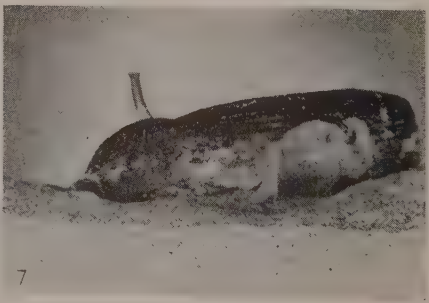

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Conus striatus normally occurs on sandy bottoms, on shallow reef platforms as well as in deeper water, throughout the Indo-Pacific region. A specimen placed in an aquarium will bury itself almost completely if sufficient sand is provided. Only the siphon may protrude from the surface of the sand. The siphon continually directs a stream of water into the mantle cavity. This water passes over the gill and osphradium, and by the anus, before leaving the mantle cavity.

The osphradium, a chemoreceptory organ, is more highly specialized in the Conidae than in any other family of gastropods.[1] It is believed that chemoreception is the sensory modality by which the snail first becomes aware of a fish placed in its tank.

Less than a minute after the fish is introduced, and in some cases within several seconds, the gastropod becomes active. The proboscis is extended up out of the sand, and movements of the foot begin raising the entire animal, although the eyes are initially below the sand-water interface.

The same behavior pattern is noted following introduction, not of a fish, but of water from an aquarium in which fish have been swimming. This observation provides further evidence for the hypothesis that the initial stimulus is chemical rather than visual. That mechanical stimulation is not the initial releaser of proboscis activity is indicated by the absence of response following agitation of the water with a glass rod. Recently killed fish (*K. sandvicensis*) did not evoke this behavior pattern, even when left in the tank for 24 hours.

When a live pelagic fish (e.g., *Kuhlia*) is introduced into the tank with the gastropod, the proboscis of the latter is directed vertically and, in a specimen measuring 115 mm. in shell length, may be extended as much as 60 mm. The single radula tooth is held within the lumen of the proboscis, its point slightly posteriad of the aperture (Fig. 2). The tip of the proboscis is often observed to "track" or follow the fish when the latter swims past within a centimeter or so of it. However, the stimulus for release of the dart is tactile, the dart not being ejected until the body of the fish comes in contact with the tip of the proboscis (Fig. 4).

When injected into the fish, the dart is not completely freed from the proboscis, but its posterior end is held tenaciously within the latter, apparently by circular muscles which contract anteriad of the terminal knob (Fig. 1) at the posterior end of the dart. The radula tooth, then, serves as a harpoon, and the impaled fish is rapidly drawn toward the mouth by longitudinal contraction of the proboscis.

Simultaneously the venom, apparently a powerful neurotoxin, quickly paralyzes the fish, which ceases struggling within several seconds. Also simultaneously, the diameter of the mouth expands from a few millimeters to more than two centimeters in order to receive the meal (Fig. 6). After engulfment (Fig. 7), the buccal cavity remains greatly distended for several hours, as the prey must be partially digested before being passed on to the less extensible regions of the alimentary tract.

In dissecting specimens of *C. catus* which had recently fed, it was noted that fishes in the pharynx and anterior crop were already partially digested. This is in marked contrast to those species of *Conus* which feed on annelids. In these snails, digestion does not begin until the food is pushed from the posterior crop into the intestine.[5]

In order to photograph the feeding process in *C. striatus*, demersal fishes (the blennies *I. gibbifrons* and *E. marmoratus*) were used as prey organisms, since they would remain more quiescent in the tank. In these cases the proboscis of *C. striatus* was extended along the surface of the substrate (Figs. 3 and 4) rather than vertically, as when a pelagic fish was the potential prey. The feeding process is shown in Figures 3–7 in photographs taken from a 16-mm. moving picture.

The venom of *C. striatus* did not affect the blennies as rapidly as it did *Kuhlia*. Blennies often struggled for a minute or more before breathing ceased and paralysis occurred.

A specimen of *E. marmoratus* 90 mm. in total length was easily consumed by a large (115-mm.) *C. striatus*. A smaller snail (shell length 81 mm.) easily consumed an *E. marmoratus* 85 mm. in total length. A specimen of *E. marmoratus* 100 mm. in total length struggled free, however, after being stung by the larger snail. Movements of the mouth and gills of this fish ceased within 2 minutes, and death followed within 5 minutes of stinging.

In the latter case the fish tore free of the dart, which remained held by the proboscis. In this instance as well as in several in which darts were ejected unsuccessfully, the proboscis, still holding the dart, was rapidly withdrawn into the mouth. Several minutes later the same dart was forced slowly out of the mouth, the process lasting 10–30 minutes. Each radula tooth, then, is used only once. If the prey is successfully captured, the tooth is swallowed with it; if not, the dart is later completely ejected and a new one is moved into place from the radula sheath.

Feeding in C. catus.—This is a smaller, intertidal species, often found on the reef flat in shallow pools isolated by the receding tide. Such pools are commonly frequented by the small blennnies and gobies on which this snail feeds.

In the laboratory, specimens were fed on the goby *B. fuscus*. The gastropods paralyzed and consumed with ease gobies equal to and somewhat greater than their own length (20–30 mm.). The feeding process is essentially identical with that described above for *C. striatus*.

Conclusion.—Two species of the gastropod genus *Conus* have been shown to prey on live fishes as their normal, and probably exclusive, source of food. This represents an ecological niche not previously known to be occupied by gastropods.

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